A STUDY OF THE FUNDAMENTAL FACTORS THAT AFFECT SEAM STRENGTH

LEO LOUIS KORNFELD

A STUDY OF THE FUNDAMENTAL FACTORS THAT AFFECT SEAM STRENGTH

A Thesis

Presented to

the Faculty of the Graduate Division

by

Leo Louis Kornfeld

In Partial Fulfillment

of the Requirements for the Degree

Master of Science in Textiles

Georgia Institute of Technology

June 1952

A STUDY OF THE FUNDAMENTAL

FACTORS THAT AFFECT SEAM STRENGTH

Approved:

ACKNOWLEDGEMENTS

On the completion of this work, I wish to sincerely express my gratitude to Dr. James L. Taylor of the Georgia Institute of Technology for his assistance and guidance. I also thank Professor C. A. Jones and Professor G. B. Fletcher for their helpful advice.

I would also like to extend my thanks to the United States Navy, Lanett Bleachery and Dye Works, Dan River Corporation, Singer Sewing Machine Company, Inc., and the American Thread Company, Inc. for their able assistance to me and for their cooperation on this problem.

I would also like to extend my thanks to my wife, Laura Kornfeld, for her help on this thesis.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

A STUDY OF THE FUNDAMENTAL FACTORS THAT AFFECT SEAM STRENGTH

ABSTRACT

In this investigation, 27 cotton fabrics of various weights and constructions were used as samples. The fabrics were tested for thread count, thickness, and tensile strength by the standard methods as described by the government specifications for textiles. In order to determine the stiffness of the fabrics, Pierce's cantilever bending method was used. From the bending length, the bending modulus was computed and it was this figure that was used as a measure of the stiffness of the fabric.

Seams were made from these fabric samples and they were all sewed under the same conditions, that is, the speed of the sewing machine, the sewing thread size, the sewing machine needle size, the stitches per inch, and the tension of the sewing thread were the same for all samples. Each sample was then tested for seam strength, yarn severance, and seam resistance to slippage. These tests were performed in a manner similar to the methods described in the government speicifications for textiles. Seam efficiency was computed from the seam strength data.

In addition, another method for determining the sewing machine needle damage was developed. The decrease in tensile strength of the fabric, because of the needle damage, was determined and this figure divided by the original tensile strength of the fabric was expressed as a percentage. This calculation was defined as sewing machine

damage and was used through the study as the measure of needle damage.

From the experimental data, linear correlations were computed between seam efficiency and each of the three variable factors, namely, sewing machine damage, seam resistance to slippage, and stiffness as measured by the bending modulus. Multiple correlation was computed between seam efficiency and these three factors, afterwhich the intercorrelations between these three factors were also computed.

From the significant results obtained from the correlation computations, it was concluded that sewing machine damage, seam resistance to slippage, and stiffness of the fabric as measured by the bending modulus, individually affect the seam strength. Also, the combination of these three factors affect the seam strength. Finally, threr is a large amount of intercorrelation between these three factors, that is, a change in any one factor will probably result in a change in the other two factors.

I

INTRODUCTION

Practically all the cloth produced in this country eventually ends up in a sewing room for further processing so that it can be formed into a saleable and useful product. Except in rare cases, there is a large gap between the companies producing the cloth and those fabricating or sewing the cloth. This gap is emphasized first, by the physical separation of the textile mill and sewing rooms; secondly, by the specialized technical knowledge required in a textile mill which varies considerably from that required in a sewing room; and finally, by the general make up which includes such items as size and financial worth of the industry.

Apparently, this situation also exists in other countries. At the recent annual conference of the Textile Institute in England, during the discussion period on L. H. Scott's paper,[1] Dr. H. A. Thomas stated,

> It was most important that the fabric development people, sewing thread and sewing machine manufactures should co-operate. This was one of the most important recent developments and the Institute should interest itself in this subject as a new branch of textile technology.

Because of this apparent gap, each respective industry is not completely cognizant of the entire problem and the sewability or seaming

---

1. Scott L. H., "Some Problems Relating to Sewing", Journal of the Textile Institute, 42(1951). 653-660.

property of a fabric is generally disregarded. The textile mill produces a fabric with a certain appearance, hand, and finish. The sewing room orders this fabric, only to ascertain after the fabric is in production, that it has poor sewability and seam strength. Because of this, production flow is interrupted and the finished product does not meet the required specifications.

It is the intention of this thesis to study, by use of the seam strength method, some of the physical properties of the fabric which determine the sewability so that this information can be utilized by both the textile mills and the sewing rooms and thereby aid in partially bridging the gap between them.

Importance of problem of seam strength:--The importance of the problem of seam strength varies directly with the end use of the product. The women's dress industry is completely indifferent to this problem of seam strength and the reason for this apathy is reflected in the method used by women to purchse their dresses. There is no argument that style pervades all other factors in the women's dress industry. If a woman could purchase a dress which is styled to suit her fancy, a few broken seams are of no importance. Therefore, it is not very uncommon for a woman to purchase a fairly high priced dress and then bring it home and mend the broken seams. Along these lines, it is also argued that a broken seam only requires a few minutes time to repair, therefore the seams in a dress are unimportant, With a philosophy such as this, the women's dress industry can afford to completely neglect the problem of seam strength.

Now, to consider a viewpoint that is on the extreme opposite end of the scale to that of the women's dress industry, namely, the use of industrial fabrics.[2] The life of many industrial products made from fabrics, such as belts, awnings, and bags, is directly dependent upon the life of the seam. In our present day competitive market, the product with the longest life will aid in a reduction of cost and because of this reduction, the product is more desirable. To the user of industrial products made of fabric, the seam strength problem is of extreme importance.

---

2. Haven, George B., Industrial Fabrics. Revised and Enlarged Edition. New York: Wellington Sears Company, 1949. p. 214.

The U.S. Military departments are vitally interested in the problem of seam strength and have released reports on this subject.[3] In addition to the ideology of obtaining the best available for the men in service, there are items of military equipage and clothing where it is an absolute necessity that the seam function properly throughout the life of the item. An example of this is impregnated clothing which is worn as protection against gas attacks. The danger of a broken seam on this type of clothing is obvious. Parachutes are another example where seam strength displays its importance. Still another example is tentage. The life of a tent is directly proportionate to the strength of the seams. Thus, as mentioned previously, the end use of a product determines the importance of seam strength and it is apparent from some of the examples cited above, that research work along the lines of improving seam strength has become a necessity.

A study of the factors that affect seam strength is an important problem because its ultimate goal will aid the textile mill and sewing rooms to produce a product with the desired appearance, hand, and finish, and in which the seams will function properly throughout the life of the product.

---

3. Frederick, Edward B. and L. Virginia Hanley, Study of Sewability Tests. Unpublished Research Report, Office of Quartermaster General, Research and Development Branch, 1948. p. 17.

Definitions:-- The following terms used throughout this thesis are defined as follows:

Bending Length - Bending Length is the measurement of stiffness that determines the length of the fabric that will bend under its own weight to a definite extent.

Bending Modulus - The bending modulus equals $12G/d^3$ where G is the flexural rigidity and d the thickness of the sample. In cotton fabrics it may be regarded as a measure of compactness and is mainly dependent on the degree of adhesion of the fibers and thread.

Flexural Rigidity - Flexural rigidity equals $w \times c^3$, where w is the weight of the fabric in ounces per square yard and c equals the bending length. The flexural rigidity is a measure of stiffness as appreciated by the fingers.

Loop Strength - Loop Strength refers to the force acting upon the loop of thread at the time of failure and is measured by looping one length of thread inside another.

Resistance to Slippage - Resistance to slippage is defined as the pounds of pull across a seam per inch of width necessary to produce a specified elongation, in inches, in excess of the normal stretch of the fabric under the same load.

Seam - A seam consists of a series of stitches joining two or more plies of a material or materials. A seam is used for joining or assembling materials in the production of an article.

Seam Efficiency - Seam efficiency is defined as a percentage figure and is equal to

$$\frac{\text{Seam Strength in pounds}}{\text{Tensile Strength in pounds}} \times 100$$

Seam Strength - The seam strength of a sample refers to the force acting upon a seam, at the time of fabric failure along the line of needle penetration.

Sewability - A fabric is considered sewable when a seam can be made of the fabric and this seam will display a high seam efficiency. It also connotates a fabric which can be seamed without causing undue sewing thread breakage.

Sewing Machine Damage - Sewing machine damage equals

$$\frac{\text{Tensile Strength of Fabric minus Tensile Strength of Fabric After Needle Damage}}{\text{Tensile Strength of Fabric}} \times 100$$

Stitch - A stitch is the unit of thread formation in the production of seams and stitching.

Stitching - Stitching consists of a series of stitches embodied in a material for ornamental purposes or for finishing an edge or for both.

Tensile Strength - The tensile strength of a sample refers to the force acting upon the sample at the time of failure.

<u>Yarn Severance</u> - Yarn severance equals

$$\frac{\text{Number of Completely Severed Yarns Within a Predetermined Length}}{\text{Total Number of Yarns Within the Predetermined Length}} \times 100$$

Method of attack:-- In this investigation, 27 cotton fabrics of various weights and constructions were used as samples.

The fabrics were tested for thread count, thickness, stiffness, and tensile strength. Seams were made from these fabrics and all the seams were made under the same conditions, that is, the speed of the sewing machine, the sewing thread size, the sewing machine needle size, the stitches per inch, and the tension of the sewing thread were the same for all the samples. Each sample was then tested for seam strength, yarn severance, sewing machine damage, and for seam resistance to slippage. Seam efficiencies were computed from the seam strength data.

In addition to the above tests, some samples were run using a different sewing thread with all other conditions the same. This was performed in order to observe if there was a possible method for determining the maximum load that the sewing thread could take if the loop strength of the thread was known.

Upon accumulation of all the data, a multiple correlation index was computed between the seam efficiency and the sewing machine damage, the stiffness, and the seam resistance to slippage. Also, linear correlation was computed to determine the intercorrelation between the fabric properties mentioned above. A high correlation between any fabric property and seam efficiency indicates quantitatively the affect that the fabric property has on seam strength.

II

LITERATURE AND SURVEY OF PREVIOUS WORK

There is practically no literature on the subject of seam strength. However, there are a few large thread companies and sewing machine manufacturers engaged in research on this subject. The author was permitted to visit some of these companies and observe their methods and approach to this problem. These companies are pioneers in this field and have accomplished a great deal of intensive work on this subject of sewability.

One of the thread companies offers a customer service whereby they determine empirically the best thread combination to be used for any particular fabric seam. This particular company is responsible for some of the first studies on the problem of seam strength.

One of the sewing machine manufactures also aids their customers in acheiving better sewability regardless of the inherent fabric properties. They accomplish these results by ingenious devices and special sewing machine attachments. In addition, they are working on an improved design for the sewing machine needle with the intention of improving the sewability of any fabric.

III

EXPERIMENTAL PROCEDURE

Twenty-seven different cotton fabrics having different finishes and construction were obtained from the Lanett Bleachery and Dye Works and the Dan River Corporation. Plain, Corded, Oxford, Drill, Twill, Poplin, and Duck weaves were used, and the fabrics were finished in various ways such as mercerized, sanforized, Zelan treated, starched, resin treated, and printed.

Design and Finish - The design and finish of each of the fabrics are listed on Table XI.

Thread Count[4] - The thread count was determined by the use of a pick glass. The sample was laid smoothly and without tension on a flat table. The actual number of warp yarns and filling yarns in one inch were counted at five different places in the cloth and the average number of yarns per inch in the warp and filling direction respectively were calculated. The results are listed on Table XI.

Thickness[5] - The thickness of the fabric was determined by the Randall and Stickney gauge. This gauge was the dead weight type and is equipped with a dial graduated to read directly to .001 inch. The sample was placed upon the anvil of the gauge, smoothly but without tension. The presser foot was lowered upon the specimen gradually,

---

4. General Specification: Test Methods for Textiles, CCC-T-191b, Washington, D.C.: United States Government Printing Office, 1951. The method used is approximately that of Method 5050 in this publication.

5. Ibid., The method used is approximately that of Method 5030.

and without impact. It was allowed to rest upon it for ten seconds and the dial reading taken to the nearest .001 inch. No measurement was taken within one-tenth of the width of the fabric from either edge and five tests were taken from each sample. The thickness of the sample is the average of the five tests and the results are listed in Table XI.

Weight of Fabric - The weight of the fabric in ounces was determined by use of an analytical balance weighing accurately to .001 gram. Each specimen was a piece three inch square of cloth. The specimen was weighed, while under standard conditions, on the analytical balance and the results of three specimens per inch fabric were averaged. The average obtained was in grams per nine square inches and in order to convert the units to ounces per square yard, the following formula was used:[6]

$$S = \frac{45.71 \times G'}{9}$$

where S = weight per unit area (ounces per square year).
G'= weight of specimen at standard regain in grams. The results are listed in Table XI.

Tensile Strength and Seam Strength[7] - To determine the tensile strength and the seam strength of the fabrics, a Scott Model J-2 tensile strength machine was used with the autographic recording device. The face of the jaws of each clamp measured one inch by three inches and the distance between the clamps was three inches at the start of the test.

---

6. Skinkle, John H., Textile Testing. 2nd ed. New York: Chemical Publishing Company, 1949, p. 78.

7. General Specification: Test Methods for Textiles, CCC-T-191b. Washington, D.C., United States Government Printing Office, 1951. The method used is opproximately that of Method 5110.

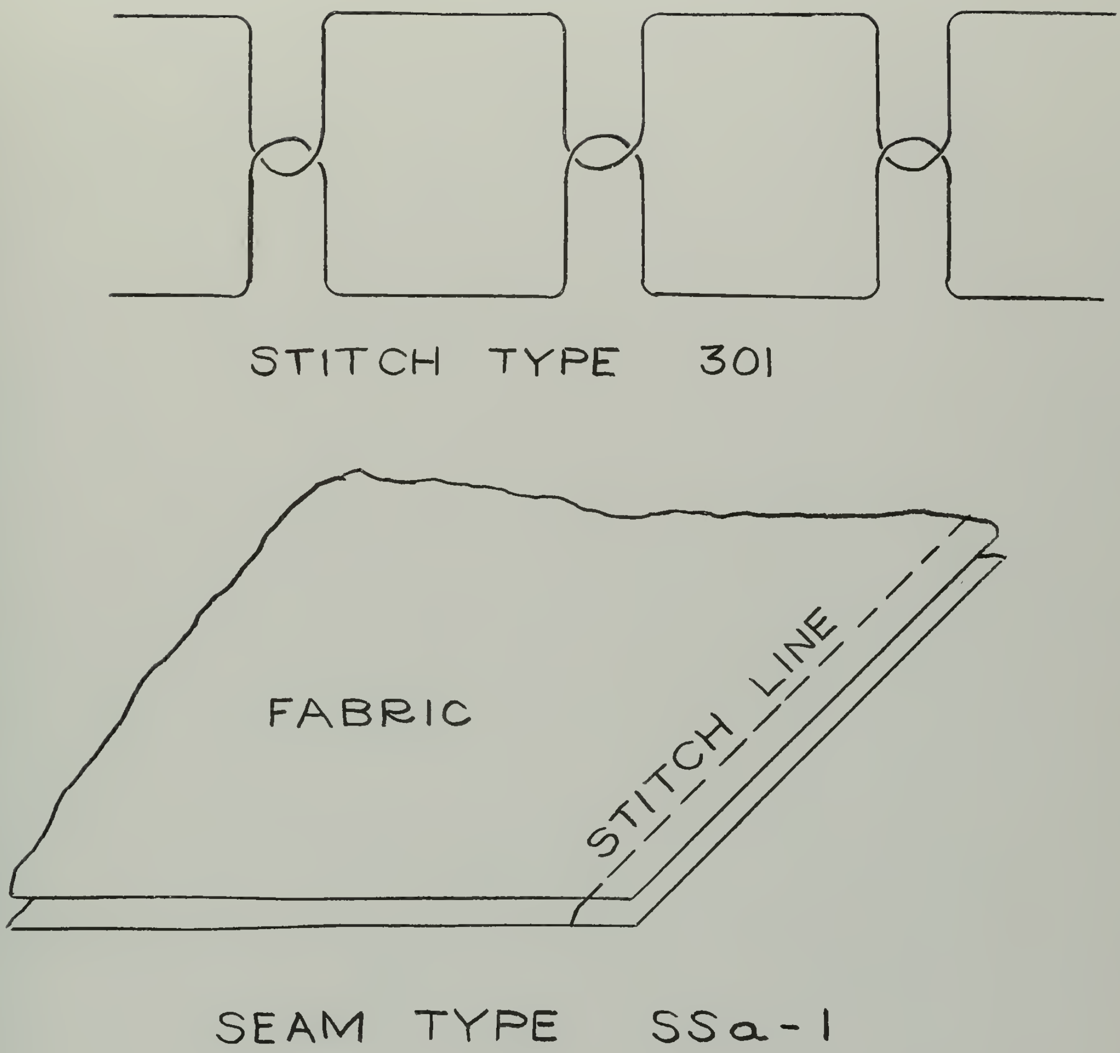
A piece of fabric, approximately 20 in. by 48 in. with the long dimension parallel to the warp, was cut into two strips of 12 in. by 48 in. and 8 in. by 48 in.

The two strips were then joined together warpwise by means of a properly formed 301 stitch and seam type SSa-1[8] (See Figure I). This type of stitch is formed by two threads. A loop of one thread is passed through the fabric where it is entered by the other thread. The loop of the first thread is drawn into the material to the extent that the concatenation is approximately halfway between the two surfaces of the material. This operation is repeated to form a sequence of stitches. To prepare this seam, a Singer Sewing Machine Model No. 241-11 was used operating at approximately 4800 revolutions per minute. A Singer 88 by 9 class needle was used, size 22, and each sample was sewed with 13 stitches per inch. Care was taken that when the two strips were placed together for sewing, they occupied as nearly as possible the same relative position as in the uncut 20 in. by 48 in. piece.

The top thread used in the sewing was a 24/4 ply glazed finish and the bottom thread was a 24/4 ply soft finish thread. The tension on the sewing thread was sufficient to form a firm stitch. The distribution of thread in the seam was 40 per cent by length, upper thread, and 60 per cent, lower thread, and the sewing was performed at the full speed of the machine. Lines parallel to the filling yarn and perpendiculat to the seam were drawn across the seamed piece at four inch intervals starting six inches from the edge where the sewing of the seam was started.

---

8. Federal Specification for Stitches, Seams, and Stitching, DDD-S-751. Washington, D.C.: United States Government Printing Office, 1935, p. 25, p. 27.



SKETCH OF THE 301 STITCH AND SEAM TYPE SSa-1.

FIGURE I

This procedure involved two breaking strength determinations which were made in pairs on the same one inch set of filling yarns. The vertical lines drawn on the specimens were used as guides. The free portion of the 12 inch strip was placed in the clamps of the Scott Tensile Strength machine, lining up the guide marks with the vertical edge of the front jaws in the top and bottom clamps. The specimen was then securely fastened by tightening the jaws, and the result read from the chart on the autographic recorder.

The jaws of the machine were then loosened and the specimen moved upward along the same filling threads until the seam was midway between the clamps perpendicular to the direction of the application of the load. Care was taken in placing of the specimen seam in the testing position to exclude from the test that portion of cloth that had been held in the jaws of the machine when determining the fillingwise strength. The guide marks of the specimen were again aligned with the same vertical edge of the jaws in both clamps as in the previous determination. The specimen was then securely fastened, the break made, and the result read from the chart on the autographic recorder. Only those tests where the failure of the seam occurred at the line of needle penetration (including slippage) were considered.

Five tests were made for each sample, that is five tests on the fabric tensile strength fillingwise, and five tests on the seam strength fillingwise, and the results averaged.

The entire procedure was repeated in the warp direction.

Table XII lists the test results on fabric tensile strength fillingwise.

Table XIII lists the test results on fabric tensile strength warpwise.

Table XIV lists the test results on the seam strength fillingwise.

Table XV lists the test results on the seam strength warpwise.

Seam Efficiency - The fabric sewability or seam efficiency was calculated as follows:

$$\text{Seam efficiency} = \frac{\text{Seam Strength (lbs.)}}{\text{Tensile Strength (lbs.)}} \times 100$$

This calculation was made warpwise and fillingwise and the results are listed in Table II.

Yarn Severance Method[9] - Upon completion of the tests described above, five three inch portions were cut from the seam and the row of sewing thread removed. No specimens were taken from within six inches of the end of the seam where the sewing operation was started. The bottom layer of fabric was used for the determination.

The edge of the fabric was cut to within one-eighth inch of the row of stitching. The middle one inch of each of the specimens were then cut out and the warp yarns removed by use of a pick needle to a point slightly below the stitching. The number of completely severed yarns were then counted and the number of warp yarns severed were counted as they were removed.

The five tests of each specimen were then averaged. This was accomplished in the warp and filling directions.

---

9. General Specification: Test Methods for Textiles, CCC-T-191b. Washington, D.C.: United States Government Printing Office, 1951. The method used is approximately that of Method 5400.

Figure 2 is a photomicrograph depicting the damage caused to a fabric by the sewing machine needle.

Figure 3 is a photomicrograph depicting a fabric undamaged by the sewing machine needle.

Table XVI lists the number of yarn severed in the seam sewed perpendicular to the warp.

Table XVII lists the number of yarn severed in the seam sewed perpendicular to the filling.

Yarn severance was calculated as follows:

$$\frac{\text{no. of yarns severed}}{\text{no. of yarns per inch}} \times 100$$

This calculation was performed both in the warp and filling direction for the seams sewed perpendicular to the warp and the filling.

Table XVIII lists the yarn severance for the seam perpendicular to the filling and for the seam perpendicular to the warp.

Seam Slippage - In performing the tensile strength and seam strength tests described above, the autographic recorder was used. Load elongation curves for the fabric and the fabric-plus-seam for each specimen were plotted on the same coordinates and started from the same origin.

Figure IV is a typical example of the appearance of a set of curves for one test. Five sets of similar curves were prepared for each sample, fillingwise.

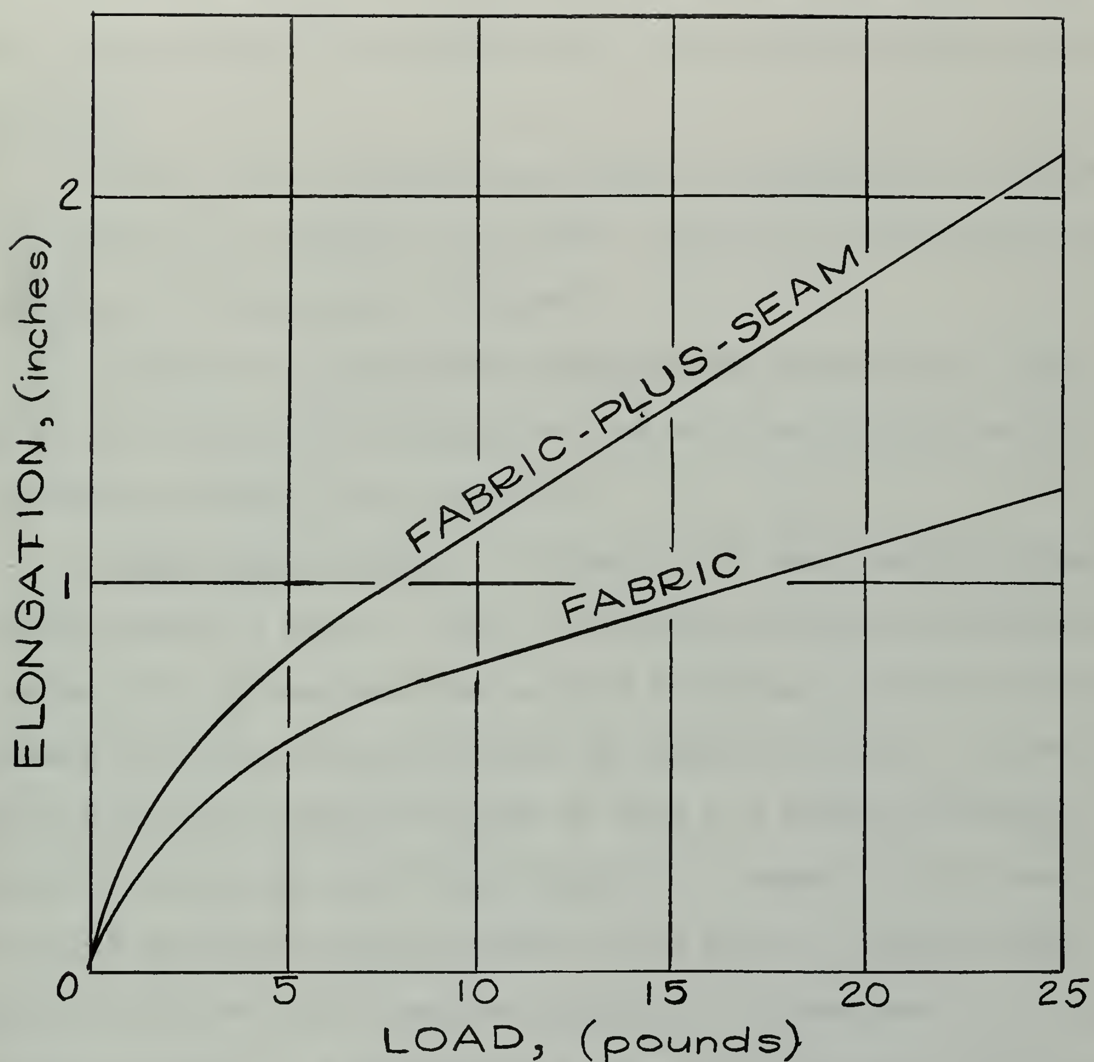
A pair of dividers were then set at one-quarter inch and with one point on the fabric curve, proceeded up this curve until the other point rested on the load elongation curve for the fabric-plus-seam with both

PHOTOMICROGRAPH OF THE FABRIC DAMAGE DUE TO SEWING MACHINE NEEDLE (22x)

Figure 2

Photomicrograph of Fabric Undamaged by Sewing Machine Needle (22x)

Figure 3



A TYPICAL LOAD VERSUS ELONGATION CURVE FOR THE FABRIC AND FABRIC-PLUS-SEAM.

FIGURE IV

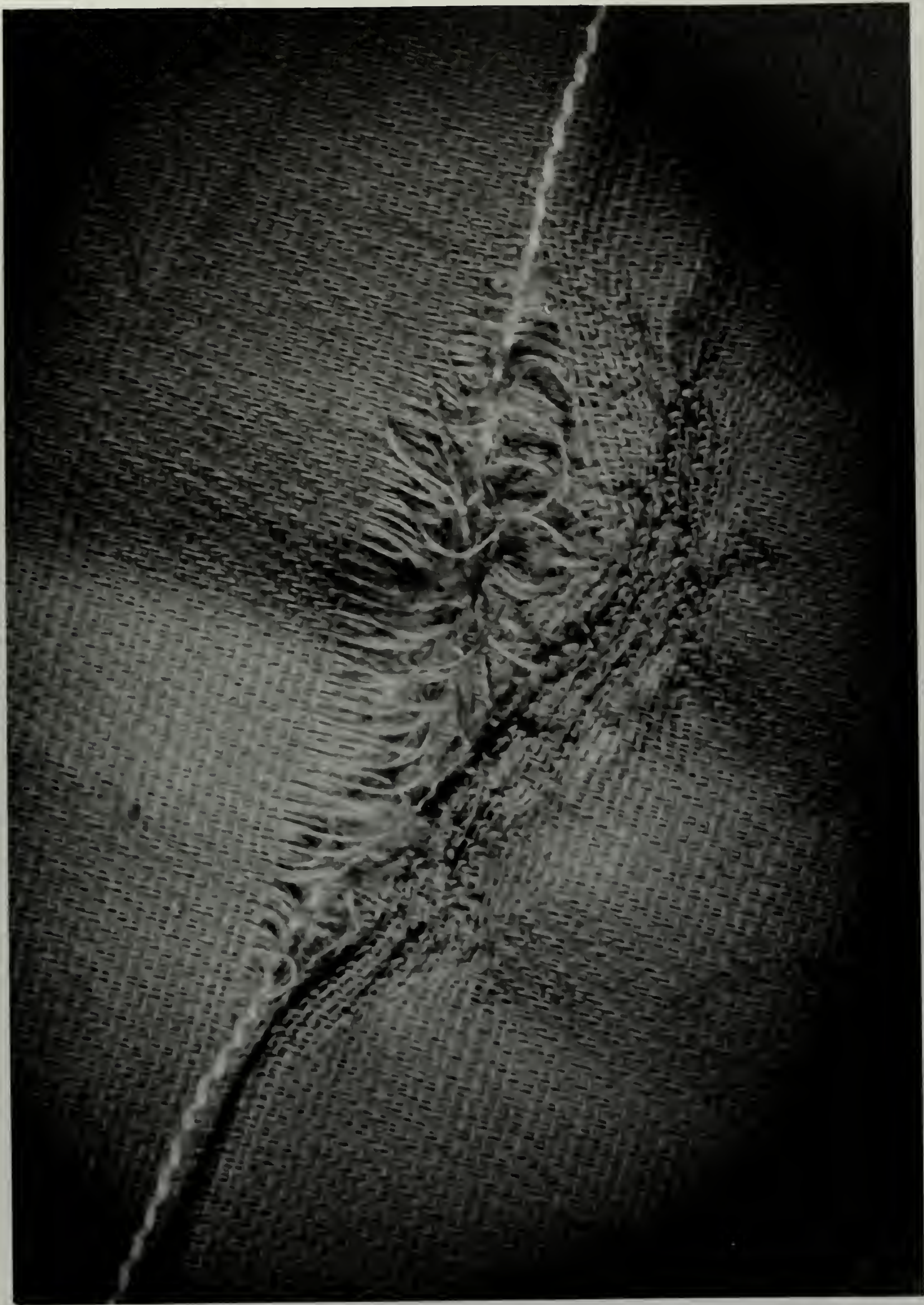
points resting on the same vertical ordinate. The force in pounds at this position is that necessary to produce a slippage of one-fourth inch on one inch of fabric width. This figure was termed resistance to slippage and five readings were made on each sample and averaged. This test was only performed on the warpwise seam. Table XIX lists the results of this test.

Figure V is a photograph indicating the appearance of a seam where the resistance to slippage was low and a distortion of the fabric yarn adjacent to the seam line is observed.

Figure VI is a photograph indicating the appearance of a seam where the resistance to slippage was high and there is practically no distortion adjacent to the seam line.

<u>Sewing Machine Damage</u> - To determine the sewing machine damage by another method, a piece of fabric approximately sixteen by thirty-six inches, with the long deminsion parallel to the warp, was cut in the warp direction into two strips each eight by thirty-six inches. The two strips were then joined together warpwise by means of a properly formed 301 stitch and seam type SSa-1[10] (See Figure I). However, in this case, the seam was made to run down the center of the fabric. A Singer Sewing Machine Model No. 241-11 was used operating at approximately 4800 revolutions per minute. A Singer 88 by 9 class needle was used, size 22, and each sample was sewed with thirteen stitches per inch. The top thread used in the sewing was a 24/4 ply glazed finish and the bottom thread was a 24/4 ply soft finish. The tension on the sewing thread was suf-

10. Federal Specification for Stitches, Seams, and Stitching, DDD-S-751. Washington, D.C.: United States Government Printing Office, 1935, p. 35, p. 27.



PHOTOGRAPH OF THE DISTORTION OF THE FABRIC YARNS ADJACENT TO THE SEAM

Figure 5

PHOTOGRAPH OF A SAMPLE WITH NO DISTORTION OF THE FABRIC YARNS ADJACENT TO THE SEAM

Figure 6

ficient to form a firm stitch. The destribution of thread in the seam was 40per cent by length, upper thread, and 60 per cent lower thread. The sewing was performed at the full speed of the machine.

The specimen was cut into five four inch panels starting six inches from the edge where the sewing of the seam was started. Then, the row of sewing thread was removed. Each specimen, top and bottom layer, was then tested for its tensile strength in accordance with the grab method. The face of the jaws of each clamp measured one inch by three inches and the distance between the clamps was three inches at the start of the test. Care was taken that the line of needle penetration was midway between the clamps perpendicular to the direction of the application of the load. Only those tests where the rupture occured at the line of needle penetration were considered. Five tests on each specimen, top and bottom layer, were averaged.

Similar tests were made on the fillingwise seam.

Table XX lists the results of these tests, warpwise, on both top and bottom layer.

Table XXI lists the results of these tests, fillingwise, on both top and bottom layer.

Sewing machine damage was computed as follows:

$$\frac{\text{Tensile Strength of Cloth} - \text{Tensile Strength after Fabric Damage by Sewing Machine Needle}}{\text{Tensile Strength of Cloth}} \times 100$$

The results of this calculation are listed on Table XXII.

Stiffness[11] - The stiffness of the fabric was tested by the cantilever bending method (Pierce Formula).[12] A photograph of the apparatus used in this test is shown in Figure VII.

The specimen was a rectangular strip of fabric six inches by one inch with the long dimension parallel to the yarns to be tested. The specimen was accurately cut from a smooth area in the fabric which had not been previously folded or in any manner deformed. Five specimens were cut with the long dimension parallel to the warp and five specimens were cut with the long dimension parallel to the filling.

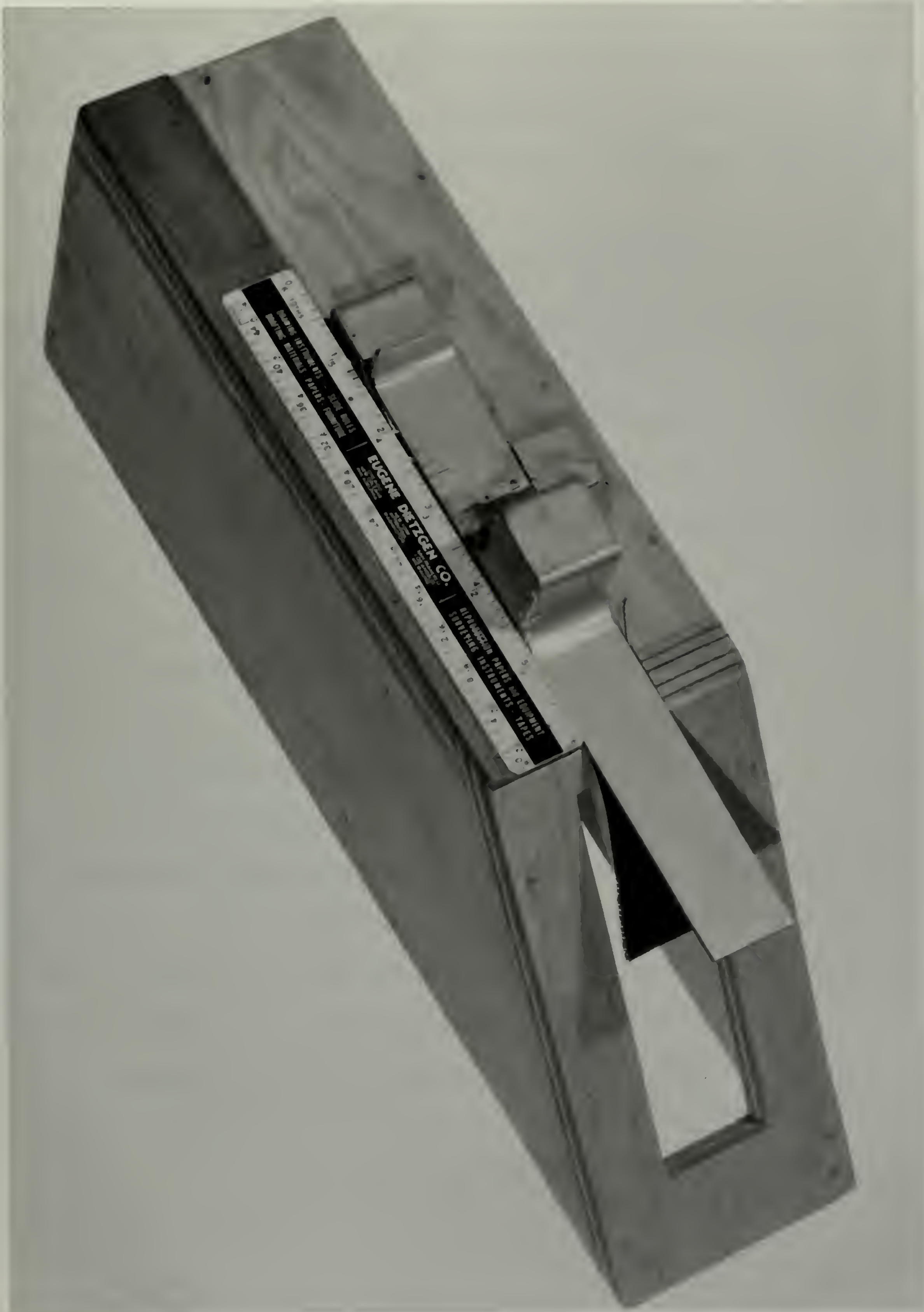
The testing apparatus was level and placed at eye height. Then, the specimen was placed lengthwise in the clamp so that the free end of the specimen was exactly even with the front end of the clamp. Both face and back surfaces were tested in warp and filling direction.

With the specimen inserted, the clamp was placed on the stand so that the reference line on the clamp exactly coincided with the zero point on the ruler. The clamp together with the specimen was moved slowly along the platform against the ruler until the free end of the specimen dropped to the 43° surface slope. A reading was then taken from the mounted ruler and this reading was the bending length of the specimen. With the long dimension parallel to the warp, five readings with the face up and five readings with back up were averaged. The results are listed in Table XXIII. The procedure was repeated for the filling yarn and the results are listed in Table XXIV.

---

11. General Specification: Test Methods for Textiles, CCC-T-191b. Washington, D.C.: United States Government Printing Office, 1951. The method used is approximately that of Method 5206.

12. Pierce, F.F. "Handle of Cloth as a Measurable Quantity", Journal of Textile Institute, 21(1930). 377-416.



PHOTOGRAPH OF THE STIFFNESS TESTER

Figure 7

Stiffness-in-any-direction[13] - After measuring the value of the bending length in the warp and filling direction, the geometric mean was used to compute the stiffness-in-any-direction. The formula used in this computation was as follows:

$$\text{Stiffness-in-any-direction} = \sqrt{C_1 C_2}$$

Where C_1 is the bending length in the warp direction and C_2 is the bending length in the filling direction.[14]

Table IV lists the results of the stiffness-in-any-direction computation.

Flexural Rigidity[15] - To compute the flexural rigidity, the following formula was used:

$$G = W \times C^3$$

where G = flexural rigidity

W = Weight of fabric in ounces per square yard

C = Stiffness-in-any-direction

Table IV lists the results of flexural rigidity computations. Each computation listed here should be multiplied by a constant multiplier .48225 x 10^{-4} in order to obtain the correct units of inch-pounds. However, since these figures are only to be used for comparative purposes, the (one half can be disregarded.)

Bending Modulus[16] - To compute the bending modulus the following

---

13. Ibid., p. 401.

14. Actually C_1 and C_2 are equal to one half of the bending length and are termed drape stiffness but for comparative purposes, the one half can be disregarded.

15. Loc. cit.

16. Ibid., p. 402

formula was used:

$$q = \frac{12\,G}{d^3}$$

Where q = the bending modulus

G = flexural rigidity

d = thickness of the sample

Table IV lists the results of the bending modulus computation. Each bending modulus computation should be multiplied by a constant multiplier $.48225 \times 10^{-12}$ in order to obtain the correct units. However, since the figures are only to used for comparative purposes, the constant multiplier can be disregarded.

Tensile Strength of Sewing Thread - Single Strand[17] - The Alfred Suter Single Strand Tester was used for this test and the standard single end sewing thread test was performed.

Forty tests were made on the 24/4 glazed finish sewing thread and forty tests were made on the 24/4 soft finish sewing thread. The results of these tests were averaged. Table XXV lists the results of these tests.

Loop Strength - The same apparatus and procedure as described above was used in the loop strength test method. However, instead of placing a single end in the clamp, a loop of the thread was made and placed in one clamp and another loop formed inside the former loop was placed in the other clamp. Forty tests were made for a loop formed from the 24/4 ply soft thread and the results averaged. Forty tests

17. General Specification: Test Methods for Textiles, CCC-T-191b. Washington, D.C.: United States Government Printing Office, 1951. The method used is approximately that of Method 4230.

were also made from a loop formed by using one end each 24/4 soft and 24/4 glazed finish thread. The results of these tests are listed in Table XXV.

Sewing Thread Load - Inasmuch as the warpwise strengths of the fabrics used were large, the thread broke before the seam did in fifteen cases. The results of these tests are listed in Table XV. Also, ten fabrics were sewed exactly as described previously except that a 24/4 soft finish thread was used in the upper, in lieu of 24/4 glazed finish. In these ten tests, the thread also broke prior to the seam and the results of these tests are listed in Table XXVI. These tests were made in order to obtain an indication of the possibility of determining the sewing thread maximum load when the loop strength of the thread is known. Also, it is thought that this information will ultimately lead to a method for determining the thread size for any specified seam strength.

It should be noted that in some tests, ten specimens were tested in lieu of five. The reason for this doubled amount was due to a large variation of the results for the particular sample.

IV

RESULTS OF EXPERIMENTAL WORK

From the experimental data, the properties of the fabric that affect seam strength were determined. The approach to this portion of the problem was to calculate linear and multiple correlations between the fabric properties and seam efficiency.

Table I lists the tensile strength and seam strength, fillingwise and warpwise, for each sample. The individual data for these tests may be found in Tables XII, XIII, XIV, and XV of the Appendix of this report.

Table II lists the seam efficiency, fillingwise and warpwise, for each sample. Seam efficiency was computed from the tensile and seam strength data listed in Table I.

Table III lists the yarn severance and sewing machine damage, fillingwise and warpwise, for each sample. The individual data for these tests may be found in Tables XVI, XVII, XVIII, XX, XXI, and XXII of the Appendix of this report.

Table IV lists the stiffness-in-any-direction, flexural rigidity, and bending modulus for each sample. The individual data for these tests may be found in Tables XXIII and XXIV of the Appendix of this report.

Table V lists the seam resistance to slippage, fillingwise for each sample. The individual data of the tests may be found in Table XIX of the Appendix of this report.

Table VI lists the seam load of the samples where the sewing thread broke prior to the fabric. The seams recorded here were made by two methods, namely, where the upper thread was 24/4 ply glazed, lower thread, 24/4 ply soft; and where both the upper and lower thread were 24/4 ply soft. The data for these tests may be found in Tables XV and XXVI.

These six tables mentioned above summarize the data on which further calculations were made. However, inasmuch as the warpwise strengths of most of the fabrics were so large, the seam efficiency could not be computed because the thread broke prior to the fabric rupture. Therefore, in practically all cases, the statistical computations were made on the fillingwise data.

The formula used for computing the linear correlation was as follows:

$$r_{xy} = \frac{XY - NM_x M_y}{\sqrt{\left[\Sigma X^2 - NM^2_x\right]\left[\Sigma Y^2 - NM_y{}^2\right]}}$$

where x and y are the variables

r_{xy} = Coefficient of linear correlation between x and y

N = Number of samples

Mx = Mean of the x variable

My = Mean of the Y variable

This computation was made between seam efficiency and sewing machine damage, stiffness[18], yarn severance, and seam resistance to slippage. Also, this computation was made between sewing machine damage and yarn

18. As a measure of stiffness, the bending modulus was used. All the stiffness measures were tested and the best correlation was obtained between seam efficiency and bending modulus.

severance. Table VII includes these computations and results.

In addition to the above, intercorrelations were calculated between the bending modulus and sewing machine damage, seam resistance to slippage and sewing machine damage, and seam resistance to slippage and bending modulus. Table VIII includes these computations and results.

Table IX is a table of the correlations and the intercorrelations between the different variables.

After the linear correlations were computed and intercorrelations determined, the next step was to determine the multiple correlation between the four variables, namely, seam efficiency, seam resistance to slippage, sewing machine damage, and stiffness. The formula used for this computation was

$$R_{y(x,q,s)} = \sqrt{1 - \frac{\sigma^2_{y \cdot xqs}}{\sigma^2_y}}$$

in which $R_{y(x,q,s)}$ = the coefficient of multiple correlation

σ_y = the standard deviation of the variable Y

$\sigma_{y \cdot xqs}$ = the variablilty left in variable Y when the varibility of x, q, and s is held constant through partial correlations.

Table X shows the computation of this multiple correlation and the results thereof.

TABLE I

AVERAGE** RESULTS OF TENSILE AND SEAM STRENGTH

Sample Number	Warpwise Tensile Strength (lbs.)	Warpwise Seam Strength (lbs.)	Fillingwise Tensile Strength (lbs.)	Fillingwise Seam Strength (lbs.)
1	74.0	61.5	69.2	65.4
2	715.	62.3	67.6	52.6
3	57.8	56.5	59.2	53.2
4	67.4	58.8	58.7	50.0
5	112.1	68.6*	89.1	66.7
6	104.6	81.8*	49.8	35.7
7	120.0	78.8*	48.6	41.0
8	133.1	76.9*	84.6	64.8
9	125.2	67.1	90.5	64.6
10	75.7	63.2	43.1	35.3
11	76.1	57.3	43.6	36.7
12	97.0	47.2	29.1	22.5
13	65.5	63.7*	39.1	43.8
14	125.5	67.3*	47.4	37.6
15	81.9	63.1*	56.0	40.7
16	125.0	74.3*	93.5	68.9
17	75.6	67.5*	46.5	36.5
18	119.3	73.6*	49.7	47.5
19	108.1	77.0*	89.2	59.9
20	90.7	58.4	26.2	19.2
21	168.9	70.6*	96.7	64.1
22	69.9	55.2	44.1	40.2
23	132.0	74.3	74.6	53.5
24	73.9	66.1	51.5	45.3
25	106.6	67.8*	63.5	55.8
26	80.5	61.6	44.5	39.0
27	118.8	69.6*	83.2	61.4

* Thread broke prior to fabric.

** Average of five tests.

TABLE II

SEAM EFFICIENCY OF FABRICS TESTED

Sample Number	Warpwise (%)	Fillingwise (%)
1	83.2	94.5
2	87.2	77.8
3	97.8	89.9
4	87.0	85.2
5	*	74.9
6	*	71.7
7	*	84.4
8	*	76.6
9	*	71.4
10	83.6	81.9
11	75.3	84.2
12	48.7	77.3
13	*	100.0
14	*	79.3
15	*	72.7
16	*	73.4
17	89.5	78.5
18	*	95.6
19	*	67.2
20	64.3	73.3
21	*	66.3
22	79.1	91.2
23	*	71.7
24	89.9	88.0
25	*	80.8
26	76.6	87.6
27	*	73.8
		2169.2

Mean = 80.34

* Thread broke prior to fabric.

Typical Calculation:

$$\text{Seam efficiency} = \frac{\text{Tensile Strength of Seam}}{\text{Tensile Strength of Fabric}} \times 100$$

Therefore in sample number 1 - fillingwise

$$\frac{65.4}{69.2} \times 100 = 94.5$$

TABLE III

RESULTS OF TESTS FOR NEEDLE DAMAGE TO FABRIC

Sample Number	Warpwise Yarn Severance (%)	Warpwise Sewing Machine Damage (%)	Fillingwise Yarn Severance (%)	Fillingwise Sewing Machine Damage (%)
1	0	7.7	2.93	12.1
2	.53	10.2	4.44	23.1
3	0	0	.31	1.9
4	.29	12.9	3.32	14.3
5	.22	0	.64	6.5
6	0	0	8.96	17.7
7	.97	0	2.16	9.3
8	.48	0	3.00	14.5
9	0	0	2.68	22.1
10	0	3.0	2.78	17.6
11	1.10	0	3.00	13.8
12	0	7.1	4.74	12.7
13	0	0	.54	0
14	0	0	.73	0
15	.23	0	1.90	13.9
16	0	3.8	1.17	8.3
17	0	0	1.54	14.2
18	.56	0	.34	.2
19	0	0	2.20	11.2
20	3.59	2.3	3.08	17.6
21	0	0	0	5.1
22	0	0	2.58	8.6
23	.28	10.6	.33	2.1
24	0	0	0	11.8
25	0	0	0	10.2
26	.80	18.3	3.08	21.8
27	1.94	38.0	3.27	23.1

TABLE IV

RESULTS OF STIFFNESS TESTS

Sample Number	Warp Times Filling Bending Length	Stiffness in Any Direction	Flexural Rigidity	Bending Modulus
1	3.90	1.98	41.90	2.29
2	2.70	1.64	21.08	3.47
3	3.42	1.85	20.76	1.68
4	2.70	1.64	20.95	2.51
5	6.00	2.45	172.28	.94
6	4.00	2.00	58.24	3.18
7	3.96	1.99	55.32	3.02
8	5.04	2.25	101.37	2.09
9	4.20	2.05	75.17	1.84
10	4.09	2.02	44.00	3.06
11	3.23	1.80	33.76	2.34
12	6.35	2.51	83.32	4.55
13	2.43	1.56	19.14	1.05
14	2.83	1.68	52.66	.23
15	3.60	1.90	45.00	2.00
16	5.63	2.37	129.87	1.95
17	3.52	1.87	34.65	2.41
18	3.60	1.90	59.13	1.44
19	6.48	2.55	169.78	2.20
20	7.67	2.77	117.30	6.41
21	4.41	2.10	77.04	3.37
22	3.52	1.87	34.13	2.37
23	5.52	2.35	114.27	1.71
24	3.08	1.76	27.79	1.52
25	3.61	1.90	63.66	.72
26	7.87	2.80	153.65	5.46
27	6.00	2.45	120.35	3.52

Typical Calculation:

Stiffness in any Direction =

$$\sqrt{\text{Warp Bending Length} \times \text{Filling Bending Length}}$$

$$\text{Flexural Rigidity} = \text{Weight (ounces per square yard)} \times (\text{Stiffness in any direction})^3$$

$$\text{Bending modulus} = \frac{12 \times \text{flexural rigidity}}{\text{thickness}}$$

TABLE IV (Con't)

Thus, for sample number 1:

warp bending length $\doteq$ 2.05

filling bending length = 1.90

$\therefore$ stiffness-in-any-direction $= \sqrt{2.05 \times 1.90}$

$= 1.98$

Since weight in ounces per square yard = 5.40

Flexural rigidity $= 5.40 \times (1.98)^3 = 41.90$

And since the thickness $\doteq$ .013

Bending modulus $= \dfrac{12 \times 41.90}{(.013)^3} = 2.29$ (times a constant multiplier)

TABLE V

AVERAGE* RESULTS OF SEAM RESISTANCE TO SLIPPAGE

Sample Number	Resistance to Slippage (lbs.)
1	40
2	11
3	38
4	18
5	22
6	18
7	20
8	19
9	17
10	23
11	32
12	24
13	18
14	23
15	19
16	30
17	20
18	42
19	12
20	20
21	38
22	33
23	18
24	15
25	39
26	25
27	35

* The average of five tests.

TABLE VI

AVERAGE* RESULTS OF SEWING THREAD LOAD

Sample Number	Seam Load-Upper 24/4 Glazed Thread Lower 24/4 Soft Thread (lbs.)	Sample Number	Seam Load-Upper 24/4 Soft Thread Lower 24/4 Soft Thread (lbs.)
5	68.6	5	57.2
6	81.5	9	61.9
7	78.8	11	50.4
8	76.9	14	53.9
9	67.1	15	53.1
13	63.7	16	61.3
14	67.3	17	60.2
15	63.1	18	58.0
16	74.3	25	55.6
18	73.6	27	59.6
19	77.0		
21	70.6	Total	571.2
23	74.3		
25	67.8	Average	57.1
27	69.6		
Total	1074.2		
Average	71.6 lbs.		

* The average of five tests.

TABLE VII

CORRELATIONS BETWEEN SEAM EFFICIENCY AND FABRIC PROPERTIES

CORRELATION BETWEEN SEAM EFFICIENCY AND SEWING MACHINE DAMAGE

X = Sewing machine damage (Fillingwise)

Y = Seam efficiency (Fillingwise)

$M_x = 11.62$

$M_y = 80.34$

$\Sigma X^2 = 4945.7$

$\Sigma Y^2 = 176{,}335.1$

$\Sigma XY = 24{,}690.8$

$$r_{xy} = \frac{24{,}690.8 - 27(11.62)(80.34)}{\sqrt{\left[4945.7 - 27(11.62)^2\right]\left[176{,}335.1 - 27(80.34)^2\right]}}$$

$$r_{xy} = \underline{\underline{-.315}}$$

CORRELATION BETWEEN SEAM EFFICIENCY AND BENDING MODULUS

Q = Bending modulus

Y = Seam efficiency (Fillingwise)

$M_q = 2.49$

$M_y = 80.34$

$\Sigma Q^2 = 217.50$

$\Sigma Y^2 = 176{,}335.1$

$\Sigma QY = 53{,}414.0$

$$r_{qy} = \frac{53{,}414.0 - 27(2.49)(80.34)}{\sqrt{\left[217.50 - 27(2.49)^2\right]\left[176{,}335.1 - 27(80.34)^2\right]}}$$

$$r_{qy} = \underline{\underline{-.498}}$$

TABLE VII (Cont'd)

CORRELATION BETWEEN SEAM EFFICIENCY AND SEAM RESISTANCE TO SLIPPAGE

S = Seam resistance to slippage (Fillingwise)

Y = Seam efficiency (Fillingwise)

$M_s = 25.1$

$M_y = 80.34$

$\Sigma S^2 = 19,231.0$

$\Sigma Y^2 = 176,335.1$

$\Sigma SY = 55,209.1$

$$r_{sy} = \frac{55,209.1 - 27(25.1)(80.34)}{\sqrt{\left[19,321.0 - 27(25.1)^2\right]\left[176,335.1 - 27(80.34)^2\right]}}$$

$r_{sy} = .356$

CORRELATION BETWEEN FILLINGWISE SEWING MACHINE DAMAGE AND YARN SEVERANCE

X = Sewing machine damage

F = Yarn severance

$M_x = 11.62$

$M_f = 2.21$

$\Sigma X^2 = 4945.7$

$\Sigma F^2 = 229.49$

$\Sigma FX = 924.37$

$$r_{fx} = \frac{924.37 - 27(2.21)(11.62)}{\sqrt{\left[4945.7 - 27(11.62)^2\right]\left[229.49 - 27(2.21)^2\right]}}$$

$r_{fx} = .726$

TABLE VII (Cont'd)

CORRELATION BETWEEN SEAM EFFICIENCY AND YARN SEVERANCE

Y = Seam efficiency (Fillingwise)

F = Yarn severance (Fillingwise)

$M_y = 80.34$

$M_f = 2.21$

$\Sigma Y^2 = 176{,}335.1$

$\Sigma F^2 = 229.49$

$\Sigma FY = 4{,}674.31$

$$r_{fy} = \frac{4{,}674.31 - 27(2.21)(80.34)}{\sqrt{\left[176{,}335.1 - 27(80.34)^2\right]\left[229.49 - 27(2.21)^2\right]}}$$

$r_{fy} = .266$

TABLE VIII

INTERCORRELATIONS BETWEEN FABRIC PROPERTIES

CORRELATION BETWEEN BENDING MODULUS AND SEWING MACHINE DAMAGE

X = Sewing machine damage (Fillingwise)

Q = Bending modulus

$M_x = 11.62$

$M_q = 2.49$

$\Sigma X^2 = 4945.7$

$\Sigma Q^2 = 217.50$

$\Sigma XQ = 935.09$

$$r_{qx} = \frac{935.09 - 27(2.49)(11.62)}{\sqrt{\left[4945.7 - 27(11.62)^2\right]\left[217.50 - 27(2.49)^2\right]}}$$

$r_{qx} = .603$

CORRELATION BETWEEN SEAM RESISTANCE TO SLIPPAGE AND SEWING MACHINE DAMAGE

S = Seam resistance to slippage (Fillingwise)

X = Sewing machine damage (Fillingwise)

$M_s = 25.1$

$M_x = 11.62$

$\Sigma S^2 = 4945.7$

$\Sigma SX = 71,398.3$

$$r_{sx} = \frac{7,398.3 - 27(28.1)(11.62)}{\sqrt{\left[19,231.0 - 27(25.1)^2\right]\left[4945.7 - 27(11.62)^2\right]}}$$

$r_{sx} = -.280$

TABLE VIII (Cont'd)

CORRELATION BETWEEN SEAM RESISTANCE TO SLIPPAGE AND BENDING MODULUS

S = Seam resistance to slippage (Fillingwise)

Q = Bending modulus

$M_s = 25.1$

$M_q = 2.49$

$\Sigma S^2 = 19,231.0$

$\Sigma Q^2 = 217.50$

$\Sigma QS = 1655.2$

$$r_{qs} = \frac{1655.2 - 27(2.49)(25.1)}{\sqrt{\left[19,231.0 - 27(25.1)^2\right]\left[217.50 - 27(241)^2\right]}}$$

$r_{qs} = -.097$

TABLE IX

SUMMARY OF CORRELATIONS

	Sewing Machine Damage	Bending Modulus	Seam Resistance to Slippage
Seam Efficiency	—.315	—.498	.356
Sewing Machine Damage	———	.603	— .280
Bending Modulus	———	———	— .097

TABLE X

MULTIPLE CORRELATION BETWEEN SEAM EFFICIENCY AND FABRIC PROPERTIES

Let Y = Seam efficiency (Fillingwise)

X = Sewing machine damage (Fillingwise)

Q = Bending Modulus

S = Seam resistance to slippage (Fillingwise)

N = Number of samples

$$y = \sqrt{\frac{\Sigma yz}{N}} = \sqrt{\frac{176,335.1}{27}} = 80.8$$

$$r_{yx} = -.315$$

$$r_{yq} \cdot s = \frac{r_{yq} - r_{ys} r_{qs}}{\sqrt{1 - r^2_{yq}}\sqrt{1 - r^2_{qs}}} = \frac{-.498 - (-.315)(.603)}{\sqrt{1 - (-.315)^2}\sqrt{1 - (.603)^2}}$$

Using the same formula as above, we obtain:

$$r_{ys} \cdot x = .294$$

$$r_{sq} \cdot x = .094$$

And since

$$r_{ys} \cdot xq = \frac{r_{ys} \cdot x - r_{yq} \cdot s\, r_{sq} \cdot x}{\sqrt{1 - r^2_{yqs} \cdot s}\sqrt{1 - r^2_{sq} \cdot x}}$$

$$\therefore r_{ys} \cdot xq = .365$$

Since $\quad y \cdot xqs = x\sqrt{1 - r^2_{yx}}\sqrt{1 - r^2_{yq} \cdot x}\sqrt{1 - r^2_{ys} \cdot xq}$

$$y \cdot xqs = 80.8\sqrt{1 - (2.315)^2}\sqrt{1 - (.405)^2}\sqrt{1 - (.365)^2}$$

$$= 64.96$$

Since $\quad r_{y(x,q,s)} = \sqrt{1 - \frac{\sigma^2 y \cdot xqs}{\sigma^2 y}} = \sqrt{1 - \frac{4219.80}{6523.64}}$

$$= \underline{\underline{.595}}$$

V

DISCUSSION OF RESULTS

Experimental results and calculations show that there is a definite relationship between seam strength (as measured by seam efficiency) and the fabric properties, namely sewing machine damage, bending modulus (stiffness) and seam resistance to slippage. The significant multiple correlation of .595 gives the relationship between seam efficiency on one hand and the combination of the remaining variables on the other hand.

The significance of this jultiple correlation was tested against the null hypothesis[19]. Only once in twenty trial would a multiple correlation of .479 arise by sampling fluctuations and only once in 100 trials would a multiple correlation of .574 occur[20]. Since the multiple correlation of .595 is larger than .574, therefore it is highly significant and it can be safely inferred from the results that seam strength is affected by the sewing machine damage, bending modulus (stiffness), and seam resistance to slippage.

From Table VII, the relationship between each of the fabric properties, individually, and the seam efficiency can be observed. These results indicate that as the bending modulus (stiffness) increases, seam efficiency decreases, (the linear correlation between these two variables

---

19. Garrett, Henry E., Statistics in Psychology and Education. New York: Longmans, Green, and Company, 1947. p. 426.

20. Ibid., p. 426-7.

equals —.498); as the sewing machine damage increases, the seam efficiency decreases, (the linear correlation between these two variables equals —.315); and, as the seam resistance to slippage increases, the seam efficiency increases, (the linear correlation between these two variables equals .356).

From Table IX, it was also observed that not only do the variables affect seam strength, but that there is a sizeable intercorrelation between the variables. That is, if any one particular variable is changed, the chances are that the other variables will be affected. Thus, it can be safely inferred from the results that the variables, sewing machine damage, bending modulus (stiffness), and seam resistance to slippage affect the seam efficiency and are interrelated to one another.

In Table VII it was shown that there was a significant correlation between yarn severance and sewing machine damage. Although the yarn severance can be used as a measure of sewing machine damage, it is inaccurate compared to the method described herein for determining this damage. By the yarn severance method, only the yarns that have been completely severed can be determined and the damaged yarns cannot be measured quantitatively. In addition, the yarn severance method does not consider, in calculating the damage, the severed warp yarns when the seam is made perpendicular to the filling or vice versa. The sewing machine damage method used in this investigation overcomes the above-mentioned difficulties and more accurate results are obtained. Even in lap seams or Lsc-2 seam[21] a more accurate measure of sewing machine damage could be

---

21. Federal Specification for Stitches Seams, and Stitching., DDD-S-751. Washington, D. C., U.S. Government Printing Office, 1930. p. 38.

obtained than by the use of the yarn severance method. To use the proposed method on a lap seam, four plies of the fabric could be sewed with a single needle machine and then the stitching removed threrfrom. Each ply would be tested to determine the decrease in tensile strength because of the sewing machine damage.

In the warpwise seam strength tests, the sewing thread broke prior to the fabric in fifteen samples. The same seam strength test was repeated with all the conditions remaining the same except that a 24/4 ply soft sewing thread was substituted for the 24/4 ply glazed sewing thread in the upper. Table VI lists the poundage required for these thread breaks. The interesting point about these two tests is that if the loop strength of the sewing thread combination is multiplied by a number two less than the number of stitches per inch, the average value of the sewing thread maximum load is obtained, approximately. For example, with a thread combination of 24/4 ply glazed in the upper and a 24/4 ply soft in the lower, the average value of the sewing thread maximum load is 71.6 pounds. The loop strength of this combination is 6.69 pounds and thirteen stitches per inch were used. Therefore,

$$11 \times 6.69 = 73.6 \text{ pounds}$$

This result compares very favorably with the value 71.6 pounds as obtained by the seam strength method.

In the other example where all conditions were the same except for the upper thread, the sewing thread maximum load was 57.1. The loop strength of this combination equals 5.60. Therefore,

$$11 \times 5.60 = 61.6$$

This result also compares favorably with the sewing thread maximum load

of 57.1, determined by the seam strength method.

Apparently, with only these few cases a formula cannot be proposed. However, the results warrant further investigation. This phenomenon could be used as a stepping stone for developing a simple method for determining the most efficient sewing thread size for a particular fabric. Perhaps by predicting the maximum load that any combination of threads would withstand, and knowing other properties of the fabric itself, it might be very possible to determine the proper thread size for any desired seam strength by a few simple tests.

During the testing, many seam breaks were observed very carefully under a magnifying glass and the following theory for a seam break is offered:

As a force is exerted on the seam, the sewing thread is extended and exerts on equal force on the yarns of the fabric. The sewing thread groups the yarn in the fabric and the number of yarns in the group depend upon the stitch size. As the force increases, the sewing thread increases its force on the yarn by an equal amount. Because of the force, however, the yarns are pulled by the stitch. At the same time, the force on the thread does not permit the yarn in the fabric running parallel to the seam to move with the other set of yarns. Thus, we have the distorting effect adjacent and parallel to the seam. After the load reaches a certain point, however, the sewing threads with the distorted yarn adjacent to the seam hold one end of the yarn and no longer permit the slippage. Thus, the situation reduces itself to the point where one end of the yarn is being held stationary and a force is applied to the other end. This situation soon causes the yarn

breaking or slipping apart. As this occurs, the same load is redistributed among the other ends and because of the excess load, they break. This continues until a complete seam break results.

If, at any particular point when the load is being applied, the sewing thread maximum load point is reached, the sewing thread breaks prior to the seam.

Also, if any yarn is damaged by the sewing machine, it does not carry its share of the load and the remaining yarns have to withstand an extra load immediately. Thus, the seam strength is reduced.

From the above explanation, it would be expected that yarn severance and slippage of the yarns affect the seam strength. The results obtained in this study appear to verify this fact.

VI

CONCLUSIONS

From the results obtained in this study, it can be concluded that at least three factors, stiffness (as measured by the bending modulus), seam resistance to slippage, and sewing machine damage should be considered in producing a fabric with a high degree of seam efficiency. This conclusion is based on the following facts:

1. There is a significant linear correlation index between seam efficiency and bending modulus. This correlation index shows definitely that the stiffness (as measured by the bending modulus) affects the seam strength of the fabric.

2. There is a significant linear correlation index between seam efficiency and seam resistance to slippage. This correlation index also shows definitely that the seam strength of the fabric is directly related to the seam resistance to slippage.

3. There is a significant linear correlation between seam efficiency and sewing machine damage. This correlation index further shows that there is a definite relationship between seam strength and sewing machine damage.

4. There is a significant intercorrelation index between the fabric properties,(stiffness, seam resistance to slippage, and sewing machine damage.) Thus, a change in any one of these factors will probably change the other two factors which determine the seam efficiency.

5. The multiple correlation between seam efficiency on one hand and the combination of the remaining variables on the other hand is highly significant and demonstrates the fact that all the three variables together have a noted affect on seam strength.

VII

RECOMMENDATIONS FOR FURTHER STUDY

Upon completion of this study of the factors affecting seam strength, many aspects of the problem were uncovered that require further investigation. The following items are recommended for study.

1. A study, similar to this one, be undertaken. However, many more fabrics of varied constructions should be used so that the results observed herein could be substantiated on a larger scale.

2. In the determination of seam slippage, a more sensitive instrument than the autographic recorder should be used. A sensitive instrument with an enlarged graph could indicate at what point elongation of the sewing thread ceases and slippage commences. Also, a more accurate quantitative measurement of slippage could be determined. A study along these lines would determine, in a very accurate manner, the exact part slippage plays in seam strength.

3. A study to determine if the fabric properties which affect seam strength of two plies would also affect the seam strength of three or more plies of fabric.

4. A study to determine if any other fabric properties affect seam strength to as large a degree as those mentioned in this work.

5. A study to determine what processes in the textile mills, including the finishing plant, can be improved so that a fabric with good sewability will be produced and still retain the desired appearance, finish, and hand.

6. A study to develop a practical formula for determining the most efficient sewing thread size for a seam of specified strength. Although there are many apparent blocks, it is felt that an equation can be determined which would have wide practical usage.

BIBLIOGRAPHY

Abbott, N.J. "The Measurement of Stiffness in Textile Fabrics", Journal of Textile Research, 21(1951). 435-41.

American Society for Testing Materials Standards of Testing Materials. Philadelphia, Pa.: American Society for Testing Materials Committee D-13, 1941. 256-264; 370-3.

Federal Specification for Stitches, Seams, and Stitching, DD-S-751. Washington, D.C.: United States Government Printing Office, 1930. p. 73.

Federal Specification for Thread Cotton, V-T-276b. Washington, D. C.: United States Government Printing Office, 1935.

Frederick, Edward B., and L. Virginia Hanley, Study of Sewability Tests. Unpublished Research Report, Office of Quartermaster General, Research and Development Branch, 1948. p. 17.

Garrett, Henry E., Statistics in Psychology and Education. 3rd ed., New York: Longmans, Green, and Co., 1947, p. 465.

General Specifications: Test Methods for Textiles, CCC-T-191b. Washington, D.C.: United States Government Printing Office, 1951.

Haven, George B., Industrial Fabrics. Revised and enlarged edition, New York: Wellington Sears Company, 1949, 692.

Kennedy, S.J., "The Importance of Conservation to the Textile Industry and the American Public," Papers of the American Association of Textile Technologists, 6(1951). 66-7.

Peterson, E.C., and T. Dantzig, "Stiffness in Fabrics Produced by Different Starches and Starch Mixtures and Quantitative Method for Evaluating Stiffness", United States Department of Agriculture Technical Bulletin Number 108, 1929.

Pierce, F.F., "Handle of Cloth as a Measurable Quantity", Journal of Textile Institute, 21(1930). 377-416.

Saxl, I.J., Rayon and Synthetic Yarn Handbook, New York: Rayon Publishing Company, 1936. p. 549.

Saxl, I.J., "Stiffness Tester", American Dyestuff Reporter, 26(1937). 620-1.

A P P E N D I X

TABLE XI

DESCRIPTION OF COTTON FABRICS TESTED

Sample Number	Thread Count*	Thickness* (in.)	Weight** (oz./yd^2)	Design	Finish Used
1	67 x 75	.013	5.40	Plain Weave	Sanforized
2	76 x 72	.009	4.78	Plain Weave	Sanforized
3	64 x 64	.013	4.86	Plain Weave	Sanforized
4	70 x 63	.010	4.75	Plain Weave	Sanforized
5	90 x 63	.028	11.72	Corded Weave	Sanforized & Mercerized
6	138 x 57	.013	7.28	Oxford Weave	Sanforized, Mercerized, and Zelon Treated
7	145 x 58	.013	7.02	Oxford Weave	Sanforized, Mercerized, and Water Repellent
8	84 x 53	.018	8.90	Drill Weave	Sanforized & Mercerized
9	80 x 60	.017	8.73	Twill Weave	Sanforized & Mercerized
10	104 x 65	.012	5.34	Herringbone Twill Weave	Sanforized
11	90 x 62	.012	5.79	Herringbone Twill Weave	Sanforized
12	94 x 38	.013	5.27	Twill Weave	Starched
13	90 x 37	.013	5.05	Poplin Weave	Mercerized & Zelon Treated
14	109 x 49	.030	11.11	Twill Weave	Sanforized and Resin Treated
15	86 x 53	.014	6.56	Twill Weave	Sanforized & Mercerized
16	76 x 51	.020	9.75	Herringbone Twill Weave	Sanforized
17	92 x 37	.012	5.29	Poplin Weave	Mercerized & Zelon Treated
18	71 x 59	.017	8.62	Herringbone Twill Weave	Sanforized
19	94 x 34	.021	10.24	Duck Weave	Sanforized and Printed
20	94 x 39	.013	5.52	Twill Weave	Starched
21	88 x 52	.014	8.32	Twill Weave	Sanforized & Mercerized
22	102 x 62	.012	5.21	Twill Weave	Sanforized & Mercerized
23	72 x 61	.020	8.81	Herringbone Twill Weave	Sanforized and Tinted
24	88 x 38	.013	5.09	Poplin Weave	Mercerized and Water Repellent
25	92 x 44	.022	9.28	Twill Weave	Printed and Preshrunk
26	75 x 39	.015	7.00	Drill Weave	Starched
27	72 x 55	.016	8.18	Herringbone Twill Weave	Sanforized

* - Average results of five tests
** - Average results of three tests

TABLE XII

FILLINGWISE TENSILE STRENGTH

Sample Number	1	2	3	4	5	Average
	(lbs.)	(lbs.)	(lbs.)	(lbs.)	(lbs.)	(lbs.)
1	69.0	68.0	68.0	68.0	73.1	69.2
2	64.0	67.5	66.4	69.2	70.8	67.6
3	61.5	60.5	60.0	59.0	55.0	59.2
4	55.4	60.3	57.3	60.3	60.0	58.7
5	98.1	90.2	88.0	82.2	84.2	
5	85.4	89.5	87.6	92.2	93.4	89.1
6	46.9	55.2	49.4	49.7	47.8	49.8
7	50.4	50.6	51.0	48.3	42.7	48.6
8	89.6	83,6	86.6	88.3	75.0	84.6
9	90.5	97.0	88.0	93.5	86.7	
9	97.6	84.8	93.7	98.2	85.4	90.5
10	41.6	44.4	42.0	43.9	43.5	43.1
11	44.5	41.7	42.2	45.0	44.8	43.6
12	28.1	33.4	32.0	27.6	24.4	29.1
13	37.8	40.4	40.7	38.5	38.0	39.1
14	51.6	46.5	48.2	46.5	44.4	47.4
15	58.8	56.5	54.1	58.2	52.6	56.0
16	95.2	90.0	96.4	91.6	94.4	93.5
17	49.0	38.5	42.9	55.5	55.6	
17	39.5	40.5	47.4	48.0	48.3	46.5
18	54.0	46.5	54.0	45.5	48.5	49.7
19	85.2	93.5	88.9	88.3	90.2	89.2
20	21.0	29.5	25.5	29.0	26.2	26.2
21	90.5	97.1	98.6	96.9	100.5	96.7
22	41.5	42.4	41.9	48.5	46.0	44.1
23	71.3	76.6	73.6	79.2	72.4	74.6
24	50.6	52.7	54.2	47.0	53.0	51.5
25	65.6	64.0	61.8	62.8	63.5	63.5
26	40.0	46.0	43.5	42.5	50.0	44.5
27	82.0	81.0	79.0	85.0	89.0	83.2

TABLE XIII

WARPWISE TENSILE STRENGTH

Sample Number	TEST 1	2	3	4	5	Average
	(lbs.)	(lbs.)	(lbs.)	(lbs.)	(lbs.)	(lbs.)
1	77.5	72.4	69.2	73.8	76.9	74.0
2	74.2	73.3	71.5	69.4	69.0	71.5
3	53.5	60.5	56.5	58.5	60.0	57.8
4	69.9	68.8	65.7	68.5	64.0	67.4
5	131.0	139.5	140.8	132.1	129.3	112.1
6	106.5	103.0	108.4	101.2	104.1	104.6
7	120.0	110.5	119.5	128.7	121.3	120.0
8	128.9	131.1	135.4	129.8	140.1	133.1
9	124.6	110.4	112.5	109.5	118.6	
9	128.8	134.1	146.8	126.2	140.0	125.2
10	73.5	74.0	77.0	76.8	76.9	75.7
11	75.4	71.5	77.0	79.4	77.0	76.1
12	95.6	97.4	108.4	94.4	102.6	
12	88.2	108.2	86.0	103.5	85.6	97.0
13	70.9	67.2	62.0	65.9	61.5	65.5
14	128.7	111.3	132.6	115.2	126.1	
14	126.5	132.0	126.1	123.3	133.4	125.5
15	80.0	87.3	78.6	77.6	86.1	81.9
16	102.0	129.1	121.1	123.2	131.5	125.0
17	81.2	69.5	73.5	73.5	77.2	
17	79.5	77.0	69.5	73.0	82.6	75.6
18	114.8	112.3	114.4	127.7	127.2	119.3
19	108.3	111.4	110.0	106.6	104.1	108.1
20	92.0	91.5	90.5	92.5	87.0	90.7
21	107.0	170.5	165.2	170.1	168.7	168.9
22	70.9	67.6	63.1	74.8	73.2	69.9
23	125.0	135.9	130.4	135.6	133.0	132.0
24	74.6	72.3	72.5	73.4	76.7	73.9
25	109.1	108.9	98.9	107.5	108.6	106.6
26	82.5	80.5	72.5	83.5	83.5	80.5
27	118.5	124.0	114.5	121.0	116.0	118.8

TABLE XIV

FILLINGWISE SEAM STRENGTH

Sample Number	TESTS 1	2	3	4	5	Average
	(lbs.)	(lbs.)	(lbs.)	(lbs.)	(lbs.)	(lbs.)
1	64.9	65.7	65.0	67.4	64.0	65.4
2	55.7	55.0	50.0	53.0	48.9	52.6
3	54.5	55.0	54.0	48.0	54.5	53.2
4	48.8	47.9	45.8	54.8	52.7	50.0
5	70.0	62.3	63.6	61.9	65.5	66.7
6	37.9	30.9	35.5	37.6	36.6	35.7
7	43.0	42.7	42.3	38.4	38.6	41.0
8	65.0	64.8	68.8	61.3	63.9	64.8
9	65.8	68.0	67.9	60.5	61.0	64.6
10	34.2	35.9	33.5	35.0	38.1	35.3
11	32.5	32.4	33.4	35.9	36.1	36.7
12	24.0	23.5	24.7	19.2	21.2	22.5
13	46.5	47.7	41.1	47.5	36.0	43.8
14	38.3	36.5	36.5	37.4	39.4	37.6
15	44.0	42.4	40.6	39.9	36.8	40.7
16	64.4	68.2	67.0	76.2	68.5	68.9
17	41.2	36.2	36.5	30.3	38.5	36.2
18	48.0	46.3	46.5	46.9	49.8	47.5
19	55.8	60.0	66.5	60.4	56.9	59.9
20	19.3	18.2	20.4	17.0	21.2	19.2
21	55.0	63.0	63.4	60.9	63.3	
21	71.1	68.7	66.5	66.1	62.4	64.1
22	38.8	38.5	41.4	45.3	37.2	40.2
23	54.4	52.0	46.5	56.6	58.0	53.5
24	41.3	43.0	41.5	49.2	51.3	45.3
25	51.5	60.0	55.9	54.6	57.0	55.8
26	39.2	36.0	43.0	42.0	34.9	39.0
27	55.5	50.0	58.5	63.0	64.5	
27	70.0	65.0	58.8	55.0	65.0	61.4

TABLE XV

WARPWISE SEAM STRENGTH

TESTS

Sample Number	1	2	3	4	5	Average
	(lbs.)	(lbs.)	(lbs.)	(lbs.)	(lbs.)	(lbs.)
1	60.9	55.4	64.3	61.7	65.4	61.5
2	64.5	64.6	56.7	63.6	62.0	62.3
3	59.5	55.0	58.0	53.5	56.5	56.5
4	60.4	56.6	55.9	64.0	57.0	58.8
5	69.2*	63.3*	70.1*	69.0*	71.2*	68.6*
6	79.5*	84.5*	81.0*	82.0*	80.5*	81.5*
7	82.5*	70.6*	78.0*	78.7*	78.9*	78.8*
8	73.7*	71.8*	81.1*	74.2*	83.5*	76.9*
9	65.3*	66.8*	61.2*	74.5*	67.0*	67.1*
10	63.2	65.5	65.5	62.9	59.0	63.2
11	57.9	54.1	51.4	57.9	59.0	57.3
12	47.4	48.5	49.9	42.5	47.9	47.2
13	67.0*	63.8*	64.8*	61.3*	61.8*	63.7*
14	68.9*	70.8*	61.6*	60.8*	74.5*	67.3*
15	64.8*	63.2*	66.5*	60.1*	60.9*	63.1*
16	70.0*	76.0*	79.0*	70.4*	76.0*	74.3*
17	65.7	70.0	66.8	72.1	62.7	67.5
18	71.5*	73.6*	73.9*	76.2*	72.9*	73.6*
19	72.8*	70.4*	80.0*	80.9*	80.9*	77.0*
20	58.6	57.5	59.8	57.5	58.5	58.4
21	68.8*	66.5*	67.1*	74.7*	76.0*	70.6*
22	55.4	53.9	55.1	56.5	55.0	55.2
23	75.0*	71.2*	74.0*	76.0*	75.1*	74.3*
24	68.0	65.7	66.4	65.6	65.0	66.1
25	67.8*	67.9*	70.1*	66.8*	66.3*	67.8*
26	62.3	64.5	60.1	60.2	61.0	61.6
27	66.0*	62.5*	71.0*	72.5*	76.0*	69.6*

* Thread broke prior to fabric.

TABLE XVI

NUMBER OF YARNS SEVERED IN SEAM PERPENDICULAR TO WARP

Sample Number	TESTS 1	2	3	4	5	Average
1 - Warp	0	0	0	0	0	0
Filling	0	0	0	0	0	0
2 - Warp	2	0	0	0	0	.4
Filling	0	1	1	2	1	1.0
3 - Warp	0	0	0	0	0	0
Filling	0	0	0	0	0	0
4 - Warp	1	0	0	0	0	.2
Filling	0	0	0	0	0	0
5 - Warp	1	0	0	0	0	0
Filling	0	0	0	0	0	0
6 - Warp	0	0	0	0	0	0
Filling	0	0	0	0	0	0
7 - Warp	2	2	0	0	3	1.4
Filling	0	0	0	0	0	0
8 - Warp	1	0	1	0	0	.4
Filling	1	1	0	0	0	.4
9 - Warp	0	0	0	0	0	0
Filling	0	0	1	0	0	.2
10 - Warp	0	0	0	0	0	0
Filling	1	0	0	0	0	.2
11 - Warp	1	1	1	1	1	1.0
Filling	1	1	1	1	1	1.0
12 - Warp	0	0	0	0	0	0
Filling	0	0	0	0	0	0
13 - Warp	0	0	0	0	0	0
Filling	0	0	0	0	0	0
14 - Warp	0	0	0	0	0	0
Filling	0	0	0	0	0	0
15 - Warp	1	0	0	0	0	.2
Filling	0	0	0	0	0	0
16 - Warp	0	0	0	0	0	0
Filling	2	1	1	1	3	1.6
17 - Warp	0	0	0	0	0	
Filling	0	0	0	0	0	
18 - Warp	0	0	1	1	0	.4
Filling	2	0	0	0	2	.8
19 - Warp	0	0	0	0	0	0
Filling	0	0	0	0	0	0
20 - Warp	1	1	0	0	0	.4
Filling	1	1	1	1	3	1.6
21 - Warp	0	0	0	0	0	0
Filling	0	0	0	0	0	0

TABLE XVI (Cont'd)

Sample Number	1	2	3	4	5	Average
22 - Warp	0	0	0	0	0	0
Filling	0	0	0	0	0	0
23 - Warp	0	0	0	1	0	C
Filling	0	1	1	0	0	.4
24 - Warp	0	0	0	0	0	0
Filling	0	0	0	0	0	0
25 - Warp	0	0	0	0	0	0
Filling	0	0	0	0	0	0
26 - Warp	0	2	1	0	0	.6
Filling	1	1	1	1	2	1.2
27 - Warp	1	2	0	1	2	1.4
Filling	2	0	0	1	0	.6

TABLE XVII

NUMBER OF YARNS SEVERED IN SEAM PERPENDICULAR TO FILLING

Sample Number	TESTS 1	2	3	4	5	Average
1 - Warp	0	0	0	0	0	0
Filling	2	3	2	2	2	2.2
2 - Warp	0	0	0	0	1	.2
Filling	3	4	4	2	3	3.2
3 - Warp	0	0	0	0	0	0
Filling	0	0	1	0	0	.2
4 - Warp	1	0	0	0	0	.2
Filling	2	2	4	1	1	2.0
5 - Warp	0	0	0	0	0	0
Filling	1	0	0	0	1	.4
6 - Warp	1	0	0	0	0	.2
Filling	7	3	3	7	6	5.2
7 - Warp	1	0	0	0	1	.4
Filling	1	1	1	2	1	1.2
8 - Warp	0	0	0	0	1	.2
Filling	3	2	2	1	0	1.6
9 - Warp	1	0	0	0	1	.4
Filling	1	3	0	4	0	1.6
10 - Warp	0	1	0	1	1	.6
Filling	0	1	4	2	2	1.8
11 - Warp	1	0	0	0	0	.2
Filling	2	2	1	1	3	1.8
12 - Warp	1	0	1	0	0	.4
Filling	3	0	4	2	0	1.8
13 - Warp	0	0	0	0	0	0
Filling	0	1	0	0	0	.2
14 - Warp	2	1	2	0	1	1.2
Filling	0	1	1	0	0	.4
15 - Warp	0	2	0	2	2	1.2
Filling	1	1	1	1	1	1.0
16 - Warp	0	1	1	2	0	.8
Filling	0	1	0	0	2	.6
17 - Warp	0	0	0	0	0	0
Filling	1	0	1	0	1	.6
18 - Warp	0	2	0	0	0	.4
Filling	1	0	0	0	0	.2
19 - Warp	1	0	0	0	1	.4
Filling	1	1	1	0	1	.8
20 - Warp	1	0	2	0	0	.6
Filling	0	2	0	2	2	1.2
21 - Warp	0	0	0	0	0	0
Filling	0	0	0	0	0	0

TABLE XVII (Cont'd)

Sample Number	1	2	3	4	5	Average
22 - Warp	0	0	0	0	0	0
Filling	1	1	3	2	1	1.6
23 - Warp	0	1	0	0	0	.2
Filling	0	1	0	0	0	.2
24 - Warp	0	0	0	0	0	0
Filling	0	0	0	0	0	0
25 - Warp	1	1	0	0	0	.4
Filling	0	0	0	0	0	0
26 - Warp	1	2	0	0	0	.6
Filling	2	1	1	0	3	1.2
27 - Warp	1	0	1	3	0	1.0
Filling	3	1	2	2	1	1.8

TABLE XVIII

YARN SEVERANCE

Sample Number	Yarn Severance in Seam Perpendicular to Filling		Yarn Severance in Seam Perpendicular to Warp	
	Warp (%)	Filling (%)	Warp (%)	Filling (%)
1	0	2.93	0	0
2	.26	4.44	.53	1.39
3	0	.31	0	0
4	.29	3.18	.29	0
5	0	.64	.22	0
6	.44	9.13	0	0
7	.28	2.07	.97	0
8	.24	3.02	.48	.71
9	.50	2.66	0	.33
10	.58	2.77	0	.31
11	.22	2.91	1.10	1.61
12	.43	4.74	0	0
13	0	.54	0	0
14	1.10	.82	0	0
15	1.39	1.82	.23	0
16	1.05	1.17	0	3.14
17	0	1.62	0	0
18	.56	.34	.56	1.35
19	.43	2.35	0	0
20	.64	3.08	3.59	.43
21	0	0	0	1.15
22	0	2.58	0	0
23	.28	.33	.28	.66
24	0	0	0	0
25	.43	0	0	0
26	.80	3.08	.80	3.08
27	1.39	3.27	1.94	1.09

TABLE XIX

FILLINGWISE SEAM RESISTANCE TO SLIPPAGE

TESTS

Sample Number	1	2	3	4	5	Average
	(lbs.)	(lbs.)	(lbs.)	(lbs.)	(lbs.)	(lbs.)
1	30	40	45	45	40	40
2	17	12	10	8	7	11
3	45	39	35	38	33	38
4	20	20	15	18	17	18
5	25	20	25	20	19	22
6	20	20	15	15	21	18
7	20	20	25	19	18	20
8	34	30	28	30	25	29
9	15	20	20	15	16	17
10	25	20	25	25	18	23
11	30	35	32	32	30	32
12	25	25	25	20	25	24
13	20	10	15	25	18	18
14	25	20	25	25	20	23
15	20	20	20	20	15	19
16	25	35	35	23	30	30
17	15	25	25	15	19	20
18	45	39	40	40	45	42
19	6	7	15	15	15	12
20	25	25	20	15	16	20
21	40	37	35	42	38	38
22	35	30	30	35	32	33
23	25	15	15	20	15	18
24	10	20	22	10	15	15
25	40	40	40	35	40	39
26	20	25	25	30	25	25
27	38	27	36	37	36	35

TABLE XX

WARPWISE TENSILE STRENGTH AFTER FABRIC DAMAGED
BY SEWING MACHINE NEEDLE

Sample Number	Tests 1 (lbs.)	2 (lbs.)	3 (lbs.)	4 (lbs.)	5 (lbs.)	Average (lbs.)
1 - Top Ply	68.1	69.8	76.6	69.2	68.1	70.4
Bottom Ply	66.5	69.6	69.0	63.9	66.3	66.8
2 - Top Ply	58.0	66.5	65.0	58.4	62.0	62.0
Bottom Ply	66.7	66.3	68.9	66.5	63.0	66.3
3 - Top Ply	*	*	*	*	*	*
Bottom Ply	*	*	*	*	*	*
4 - Top Ply	62.1	58.7	55.5	54.4	63.0	58.7
Bottom Ply	*	*	*	*	*	*
5 - Top Ply	*	*	*	*	*	*
Bottom Ply	*	*	*	*	*	*
6 - Top Ply	*	*	*	*	*	*
Bottom Ply	*	*	*	*	*	*
7 - Top Ply	*	*	*	*	*	*
Bottom Ply	*	*	*	*	*	*
8 - Top Ply	*	*	*	*	*	*
Bottom Ply	*	*	*	*	*	*
9 - Top Ply	*	*	*	*	*	*
Bottom Ply	*	*	*	*	*	*
10 - Top Ply	73.4	71.1	74.1	75.2	68.0	71.8
Bottom Ply	74.2	74.3	79.1	73.4	74.0	75.0
11 - Top Ply	*	*	*	*	*	*
Bottom Ply	*	*	*	*	*	*
12 - Top Ply	86.6	87.0	90.6	92.4	92.6	89.8
Bottom Ply	84.2	85.0	90.6	97.2	95.2	90.4
13 - Top Ply	*	*	*	*	*	*
Bottom Ply	*	*	*	*	*	*
14 - Top Ply	129.6	127.5	127.4	126.3	127.7	127.7
Bottom Ply	132.7	126.7	123.7	125.2	115.2	124.7
15 - Top Ply	95.3	94.0	93.9	94.3	93.6	94.2
Bottom Ply	91.2	90.5	90.0	90.9	91.3	90.8
16 - Top Ply	124.1	113.7	119.2	117.2	125.8	120.0
Bottom Ply	119.4	124.1	111.2	124.1	124.0	120.6
17 - Top Ply	*	*	*	*	*	*
Bottom Ply	*	*	*	*	*	*
18 - Top Ply	*	*	*	*	*	*
Bottom Ply	*	*	*	*	*	*
19 - Top Ply	*	*	*	*	*	*
Bottom Ply	*	*	*	*	*	*
20 - Top Ply	91.2	91.9	87.4	93.5	84.9	89.8
Bottom Ply	81.7	76.4	93.8	88.4	92.3	87.3

TABLE XX (Cont'd)

Sample Number	1 (lbs.)	2 (lbs.)	3 (lbs.)	4 (lbs.)	5 (lbs.)	Average (lbs.)
21 - Top Ply	*	*	*	*	*	*
Bottom Ply	*	*	*	*	*	*
22 - Top Ply	73.2	71.7	67.3	69.2	76.0	71.5
Bottom Ply	68.8	68.7	68.6	68.5	68.5	68.6
23 - Top Ply	109.0	128.6	110.7	110.8	114.6	114.7
Bottom Ply	109.5	126.6	123.2	123.5	123.2	121.2
24 - Top Ply	*	*	*	*	*	*
Bottom Ply	*	*	*	*	*	*
25 - Top Ply	*	*	*	*	*	*
Bottom Ply	*	*	*	*	*	*
26 - Top Ply	58.5	60.1	55.3	65.3	60.3	59.9
Bottom Ply	70.5	74.0	73.0	74.2	66.5	71.6
27 - Top Ply	100.9	100.8	101.6	110.2	108.7	104.4
Bottom Ply	113.6	122.0	103.7	124.1	117.8	116.2

* Fabric broke at other places than along the seam line. Thus, the assumption was made that the sample was undamaged by the sewing machine needle.

TABLE XXI

FILLINGWISE TENSILE STRENGTH AFTER FABRIC DAMAGED

BY SEWING MACHINE NEEDLE

Sample Number	TEST 1 (lbs.)	2 (lbs.)	3 (lbs.)	4 (lbs.)	5 (lbs.)	Average (lbs.)
1 - Top Ply	59.9	57.0	59.8	58.7	59.1	58.9
Bottom Ply	66.5	58.2	57.7	68.4	62.7	62.7
2 - Top Ply	51.0	52.8	53.4	54.8	51.0	52.6
Bottom Ply	44.3	55.6	52.9	55.3	48.3	51.3
3 - Top Ply	65.5	59.6	57,2	52.1	51.6	57.2
Bottom Ply	57.4	61.0	58.3	58.0	59.8	58.9
4 - Top Ply	53.1	51.7	44.4	49.9	56.0	51.0
Bottom Ply	50.8	43.2	54.1	42.9	56.9	49.6
5 - Top Ply	73.2	71.6	78.6	85.0	91.6	80.0
Bottom Ply	87,5	90.2	82.0	86.0	87.2	86.6
6 - Top Ply	42.1	38.2	38.6	46.5	40.9	41.3
Bottom Ply	43.0	41.5	39.0	39.0	40.4	40.6
7 - Top Ply	45.2	43.1	48.6	44.4	44.5	45.2
Bottom Ply	43.4	35.1	50.2	39.9	44.1	
Bottom Ply	49.4	46.5	47.6	34.0	39.9	43.0
8 - Top Ply	76.8	82.5	78.3	74.5	78.0	78.0
Bottom Ply	70.9	66.4	67.5	64.9	63.0	66.5
9 - Top Ply	76.3	84.9	87.2	86.8	82.3	83.5
Bottom Ply	76.6	78.0	79.8	76.7	75.5	77.3
10 - Top Ply	35.3	41.2	34.3	32.6	32.6	35.2
Bottom Ply	39.1	37.0	34.4	34.0	34.1	35.7
11 - Top Ply	36.9	39.0	37.8	41.0	39.9	38.9
Bottom Ply	37.3	37.2	36.4	35.0	35.5	36.3
12 - Top Ply	28.6	26.0	25.9	26.9	23.4	26.2
Bottom Ply	25.9	23.9	22.7	24.3	26.1	24.6
13 - Top Ply	42.1	43.9	41.4	34.4	42.0	40.8
Bottom Ply	*	*	*	*	*	*
14 - Top Ply	48.4	48.8	40.3	45.8	49.4	46.5
Bottom Ply	48.4	54.5	48.3	40.6	49.5	48.3
15 - Top Ply	44.8	48.9	43.4	52.9	53.5	48.7
Bottom Ply	49.2	44.6	46.9	46.7	51.2	47.7
16 - Top Ply	85.2	80.9	81.4	89.9	85.9	84.7
Bottom Ply	91.4	90.1	80.8	83.5	88.2	86.8
17 - Top Ply	35.9	40.2	40.5	39.5	43.9	40.0
Bottom Ply	37.5	39.6	38.3	43.7	39.5	39.7
18 - Top Ply	51.4	52.6	52.2	58.0	50.0	52.8
Bottom Ply	47.6	46.5	48.7	41.0	47.7	46.3
19 - Top Ply	83.3	81.5	82.6	76.3	88.2	82.4
Bottom Ply	74.9	74.2	74.0	73.6	82.6	75.9

TABLE XXI (Cont'd)

Sample Number	1 (lbs.)	2 (lbs.)	3 (lbs.)	4 (lbs.)	5 (lbs.)	Average (lbs.)
20 - Top Ply	24.4	25.6	20.6	25.2	20.4	23.2
Bottom Ply	17.5	17.2	18.0	23.2	23.9	20.0
21 - Top Ply	84.4	82.6	84.2	99.6	99.7	90.1
Bottom Ply	94.5	96.4	93.1	97.6	85.5	93.4
22 - Top Ply	43.3	40.5	35.8	43.6	38.1	40.3
Bottom Ply	*	*	*	*	*	*
23 - Top Ply	72.7	74.8	70.6	68.9	73.1	72.0
Bottom Ply	70.2	77.2	69.9	75.9	77.5	74.1
24 - Top Ply	42.6	49.8	36.3	41.0	46.1	43.2
Bottom Ply	47.0	50.6	51.1	41.9	46.9	47.5
25 - Top Ply	60.0	57.6	56.8	50.8	53.7	55.8
Bottom Ply	60.3	55.4	57.7	62.9	54.7	58.2
26 - Top Ply	33.0	37.8	37.9	36.7	36.0	36.3
Bottom Ply	31.2	34.8	33.6	32.8	33.5	33.2
27 - Top Ply	63.6	55.4	66.5	75.0	72.4	66.6
Bottom Ply	61.3	56.8	67.0	58.9	62.7	61.3

* Fabric broke at places other than along the seam line. Thus, the assumption was made that the sample was undamaged by the sewing machine needle.

TABLE XXII

SEWING MACHINE DAMAGE

Sample Number	Warpwise (%)	Fillingwise (%)
1	7.7	12.1
2	10.2	23.1
3	0	1.9
4	12.9	14.3
5	0	6.5
6	0	17.7
7	0	9.3
8	0	14.5
9	0	22.1
10	3.0	17.6
11	0	13.8
12	7.1	12.7
13	0	0
14	0	0
15	0	13.9
16	3.8	8.3
17	0	14.2
18	0	2
19	0	11.2
20	2.3	17.6
21	0	5.1
22	0	8.6
23	10.6	2.1
24	0	11.8
25	0	10.2
26	18.3	21.8
27	38.0	23.1

TABLE XXIII

STIFFNESS (BENDING MODULUS) WARPWISE

Sample Number	Tests 1	2	3	4	5	Average
	(in.)	(in.)	(in.)	(in.)	(in.)	(in.)
1 - Face Up	2.3	2.3	2.2	2.1	2.0	2.2
Face Down	1.9	1.9	1.8	1.9	1.9	1.9
2 - Face Up	1.8	1.8	1.8	1.7	1.8	1.8
Face Down	1.8	1.8	1.8	1.8	1.7	1.8
3 - Face Up	2.0	2.0	2.1	2.0	2.0	2.0
Face Down	1.8	1.8	2.0	2.0	1.9	1.8
4 - Face Up	1.7	1.8	1.8	1.8	1.9	1.8
Face Down	1.6	1.8	1.8	1.8	1.8	1.8
5 - Face Up	2.3	2.4	2.4	2.6	2.5	2.4
Face Down	2.6	2.6	2.6	2.6	2.6	2.6
6 - Face Up	2.2	2.2	2.2	2.2	2.2	2.2
Face Down	2.4	2.6	2.5	2.6	2.4	2.5
7 - Face Up	2.4	2.5	2.4	2.2	2.4	2.4
Face Down	2.4	2.4	2.4	2.3	2.4	2.4
8 - Face Up	2.8	2.9	2.8	2.7	2.7	2.8
Face Down	2.0	2.0	2.0	2.0	2.0	2.0
9 - Face Up	2.3	2.2	2.3	2.3	2.3	2.3
Face Down	1.8	1.7	1.7	1.7	1.7	1.7
10 - Face Up	2.0	1.9	1.7	2.0	2.0	1.9
Face Down	2.3	2.4	2.4	2.4	2.5	2.4
11 - Face Up	1.9	1.9	1.9	1.9	1.9	1.9
Face Down	1.8	1.9	1.9	1.9	1.9	1.9
12 - Face Up	4.3	4.5	4.3	4.1	4.2	4.3
Face Down	3.5	3.3	3.6	3.3	3.4	3.4
13 - Face Up	1.8	1.8	1.8	1.8	1.9	1.8
Face Down	1.8	1.9	1.8	1.8	1.8	1.8
14 - Face Up	2.1	2.3	2.1	2.1	2.1	2.1
Face Down	1.8	1.7	1.9	1.7	1.8	1.8
15 - Face Up	1.9	2.0	2.1	2.0	1.9	2.0
Face Down	2.0	2.1	2.0	1.8	1.9	2.0
16 - Face Up	2.9	2.9	2.9	2.8	2.7	2.9
Face Down	1.6	1.7	1.6	1.6	1.6	1.6
17 - Face Up	2.2	2.1	2.2	2.2	2.1	2.2
Face Down	2.2	2.3	2.1	2.2	2.1	2.2
18 - Face Up	2.3	2.3	2.1	2.2	2.2	2.2
Face Down	1.7	1.9	1.6	1.8	1.8	1.8
19 - Face Up	2.6	2.4	2.4	2.5	2.5	2.5
Face Down	2.4	2.3	2.2	2.3	2.2	2.3

TABLE XXIII (Cont'd)

Sample Number	1	2	3	4	5	Average
	(in.)	(in.)	(in.)	(in.)	(in.)	(in.)
20 - Face Up	4.0	4.1	4.0	4.0	3.9	4.0
Face Down	3.2	3.2	3.3	3.4	3.5	3.3
21 - Face Up	2.0	2.0	1.9	2.1	2.0	2.0
Face Down	2.5	2.3	2.3	2.3	2.3	2.1
22 - Face Up	2.1	2.0	2.0	2.1	2.0	2.0
Face Down	1.8	1.6	1.7	1.7	1.7	1.7
23 - Face Up	2.4	2.3	2.4	2.2	2.3	2.3
Face Down	2.5	2.6	2.5	2.6	2.5	2.5
24 - Face Up	2.1	2.0	2.1	2.2	2.1	2.1
Face Down	2.0	1.9	2.1	2.0	1.9	2.0
25 - Face Up	1.9	2.1	2.0	2.0	2.0	2.0
Face Down	1.6	1.8	1.9	1.8	1.9	1.8
26 - Face Up	3.5	3.6	3.6	3.7	3.7	3.6
Face Down	3.1	3.0	3.1	3.1	3.1	3.1
27 - Face Up	2.1	2.3	2.2	2.2	2.3	2.2
Face Down	2.6	2.8	2.8	2.7	2.8	2.7

TABLE XXIV

STIFFNESS (BENDING LENGTH) FILLINGWISE

TEST

Sample Number	1 (in.)	2 (in.)	3 (in.)	4 (in.)	5 (in.)	Average (in.)
1 - Face Up	1.9	1.9	2.0	2.0	2.0	2.0
Face Down	1.8	1.8	1.8	1.8	1.9	1.8
2 - Face Up	1.5	1.5	1.5	1.5	1.5	1.5
Face Down	1.5	1.5	1.4	1.4	1.5	1.5
3 - Face Up	1.8	1.6	1.7	1.8	1.7	1.7
Face Down	1.9	1.9	1.8	1.9	1.9	1.9
4 - Face Up	1.5	1.5	1.5	1.5	1.5	1.5
Face Down	1.5	1.4	1.5	1.4	1.5	1.5
5 - Face Up	2.3	2.3	2.4	2.4	2.4	2.4
Face Down	2.4	2.2	2.4	2.4	2.4	2.4
6 - Face Up	1.7	1.8	1.8	1.8	1.8	1.8
Face Down	1.5	1.7	1.7	1.6	1.7	1.6
7 - Face Up	1.7	1.7	1.7	1.7	1.7	1.7
Face Down	1.7	1.6	1.7	1.6	1.6	1.6
8 - Face Up	2.2	2.1	2.1	2.1	2.1	2.1
Face Down	2.2	2.1	2.1	2.0	2.0	2.1
9 - Face Up	2.0	2.2	2.1	2.2	2.1	2.1
Face Down	2.1	2.1	2.1	2.1	1.9	2.1
10 - Face Up	1.8	1.7	1.7	1.8	1.8	1.8
Face Down	1.9	2.1	2.2	1.9	1.9	2.0
11 - Face Up	1.7	1.7	1.7	1.7	1.7	1.7
Face Down	1.7	1.7	1.7	1.6	1.6	1.7
12 - Face Up	1.7	1.6	1.7	1.6	1.6	1.6
Face Down	1.7	1.7	1.8	1.5	1.7	1.7
13 - Face Up	1.3	1.4	1.5	1.3	1.4	1.4
Face Down	1.3	1.3	1.3	1.3	1.3	1.3
14 - Face Up	1.5	1.4	1.6	1.5	1.5	1.5
Face Down	1.4	1.4	1.5	1.4	1.4	1.4
15 - Face Up	1.9	1.8	1.8	1.8	1.7	1.8
Face Down	1.8	1.8	1.8	1.7	1.8	1.8
16 - Face Up	2.6	2.8	2.7	2.8	2.6	2.7
Face Down	2.2	2.3	2.4	2.5	2.3	2.3
17 - Face Up	1.6	1.7	1.6	1.7	1.6	1.6
Face Down	1.6	1.6	1.7	1.7	1.6	1.6
18 - Face Up	1.7	1.9	1.8	1.7	1.8	1.8
Face Down	1.7	1.8	1.8	1.8	1.7	1.8
19 - Face Up	2.8	2.6	2.7	2.8	2.4	2.7
Face Down	2.7	2.7	2.7	2.7	2.5	2.7

TABLE XXIV (Cont'd)

Sample Number	1 (in.)	2 (in.)	3 (in.)	4 (in.)	5 (in.)	Average (in.)
20 - Face Up	1.7	2.3	2.4	2.3	2.3	2.2
Face Down	1.8	1.7	2.3	2.1	2.2	2.0
21 - Face Up	2.1	2.1	2.1	2.1	2.1	2.1
Face Down	2.2	2.2	2.3	2.3	2.1	2.2
22 - Face Up	2.2	1.9	1.8	1.8	1.9	1.9
Face Down	2.0	1.8	1.9	1.9	1.9	1.9
23 - Face Up	2.4	2.3	2.3	2.3	2.3	2.3
Face Down	2.3	2.3	2.4	2.3	2.3	2.3
24 - Face Up	1.5	1.5	1.4	1.5	1.5	1.5
Face Down	1.4	1.4	1.4	1.6	1.5	1.5
25 - Face Up	1.8	1.8	1.9	1.9	2.0	1.9
Face Down	1.7	1.8	1.9	1.9	2.0	1.9
26 - Face Up	2.7	2.8	2.6	2.7	2.7	2.7
Face Down	2.0	1.9	2.1	2.1	2.1	2.0
27 - Face Up	2.0	2.1	2.1	2.1	2.2	2.1
Face Down	2.6	2.9	2.7	2.7	2.9	2.8

TABLE XXV

SINGLE END AND LOOP STRENGTH OF SEWING THREAD

Single End		Loop Strength	
24/4 Soft (lbs.)	24/4 Glazed (lbs.)	24/4 Soft / 24/4 Soft (lbs.)	24/4 Glazed / 24/4 Soft (lbs.)
3.4	3.0	6.3	6.5
3.1	5.2	6.4	6.2
3.5	5.3	6.2	6.5
3.4	5.3	6.8	7.1
3.4	5.1	5.5	6.7
2.8	4.9	5.2	6.8
3.4	5.0	5.2	6.7
3.2	5.0	6.7	6.0
3.2	4.7	6.2	7.1
3.6	5.1	6.2	6.7
3.3	5.1	5.5	6.6
3.4	5.3	5.4	6.6
3.5	5.4	5.1	6.5
3.7	5.3	5.8	6.4
3.5	5.3	5.9	6.3
3.7	5.1	6.1	6.9
3.4	4.9	6.2	7.0
3.3	4.9	5.7	7.1
3.7	5.1	5.5	7.2
3.9	4.7	5.5	7.1
2.9	5.1	5.1	7.2
2.9	5.4	5.0	6.1
3.3	5.3	5.0	6.5
3.8	5.4	5.4	6.6
3.7	5.3	5.3	6.6
3.6	5.3	5.2	6.6
3.5	4.9	5.2	6.9
3.7	5.0	6.0	7.0
3.5	5.1	5.3	7.0
3.6	5.5	5.1	6.9
3.5	5.1	5.1	7.0
3.3	5.2	5.1	6.6
3.1	5.1	5.9	6.7
3.1	5.1	5.8	6.7
3.1	5.3	5.1	6.9
3.3	4.9	5.1	6.7

TABLE XXV (Cont'd)

Single End			Loop Strength	
24/4 Soft	24/4 Glazed		24/4 Soft 2/4/ Soft	24.4 Glazed 24/4 Soft
(lbs.)	(lbs.)		(lbs.)	(lbs.)
3.3	4.9		5.2	6.0
3.4	5.1		5.1	6.6
3.3	5.3		5.9	6.7
3.7	5.2		5.5	6.6
136.0	205.2	Total	223.8	267.9
3.40	5.13	Average	5.60	6.69

TABLE XXVI

SEWING THREAD LOAD*

TEST

Sample Number	1	2	3	4	5	Average
	(lbs.)	(lbs.)	(lbs.)	(lbs.)	(lbs.)	(lbs.)
5	52.8	55.6	58.9	59.0	59.8	57.2
9	62.9	58.5	58.4	62.4	67.2	61.9
11	56.5	48.4	48.6	52.9	51.8	50.4
14	58.6	56.9	47.5	55.5	51.0	53.9
15	54.8	53.1	56.6	50.0	51.0	53.1
16	64.3	66.9	59.8	60.5	55.0	61.3
17	58.0	59.8	57.4	66.6	56.6	60.2
18	60.5	54.5	60.5	57.1	57.5	58.0
25	59.0	50.0	53.5	56.7	58.8	55.6
27	56.0	52.5	60.9	62.6	66.0	59.6

*Seams made of 24/4 ply soft thread, top and bottom, and thread broke prior to fabric.

Date Due

Thesis 17328
K8 Kornfeld
A study of the fundamental factors that affect seam strength.